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L'ANALYSE DE LA TRANSITION VERS LES ENERGIES PROPRES DANS LES PAYS EN DEVELOPPEMENT : ENJEUX, MODELISATION ET MECANISMES DE FINANCEMENT

THE ANALYSIS OF A TRANSITION TOWARD LOW CARBON TECHNOLOGIES IN DEVELOPING NATIONS: STAKES, MODELLING APPROACHES AND FINANCING MECHANISMS

Thèse pour le Doctorat ès Sciences Economiques

Présentée par

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Abstract

The objective of this doctorate thesis is to investigate the contribution of renewable technologies to energy transition in developing nations. In the theoretical framework such a contribution could be justified in two points. First, it analyses conditions, means and consequences of a modification of a fuel-based energy production scheme to a new structure based on a more sustainable-oriented pathway. Second, the analysis of energy transition provides institutional, technological, sociological and managerial frameworks strengthening the convergence toward a sustainable oriented energy paradigm through a diffusion and adoption of renewable technologies. From the existing approaches, the core of this thesis is to assume a requirement to consider a mixed approach of energy transition in developing nations through a combination of both decentralized and centralized options. The decentralized energy transition approach allows an insertion of spatial and geographical characteristics of remote locations in developing nations while the centralized approach strengthens an inclusion of developing nations in a sustainable energy paradigm. From this orientation, we propose an interdisciplinary methodology, empirically based on South Africa and Senegal in order to investigate the possible contribution of renewable technologies to energy transition. To investigate these questions, we combine a bottom-up energy modeling approach with optimization techniques through a linear programming algorithm. Our results show interests to put in place an incentive framework encouraging energy transition in developing nations. In terms of energy policies our findings have two implications. On the one hand, they insist on importance of the reliabilities of institutional structures during an implementation of renewable policy incentives in developing nations. Institutional reliability allows both an optimal coordination as well as a better planning schedule of incentive policies in order to promote energy transition in developing nations. On the other hand, our results show a requirement to carry out a tradeoff among different policy options according to efficiency and distributional effects during the energy transition. Finally in all simulated renewable deployment policies (renewable energy premium tariff, carbon tax, price-based renewable energy subsidies and renewable energy portfolio standard) we have shown that a particular attention should be paid to social welfare effects of renewable energy policies.

Keywords: Renewable energies, developing nations, incentive policies , energy modeling

Résumé

L'objectif de cette thèse est d'analyser l'apport des énergies renouvelables à la transition énergétique dans les pays en développement (PED). L'apport des énergies renouvelables à la transition énergétique dans les pays en développement se justifie à deux niveaux. Dans un premier temps il vise à étudier les conditions, moyens et conséquences de la modification des structures de production énergétique existantes basées sur les technologies fossiles vers celles intégrant les technologies propres qui sont plus respectueuses de la qualité de l'environnement. Dans un second temps, l'analyse de la transition énergétique propose une architecture institutionnelle, technologique, sociologique, réglementaire et managériale favorisant la convergence vers un système socio-technique soutenable à travers la diffusion et l'adoption des technologies renouvelables. Partant des approches existantes, l'idée fondatrice de cette thèse est d'insister sur la nécessité d'une mise en place d'une approche mixte de transition énergétique dans les pays en développement en combinant une approche décentralisée (permettant de prendre en compte les caractéristiques spatiales des zones rurales enclavées) et centralisées (permettant d'insérer les PED dans un paradigme énergétique soutenable). A partir de cette orientation, nous proposons une approche interdisciplinaire empiriquement basée sur l'Afrique du Sud et le Sénégal afin d'analyser l'apport des énergies renouvelables à la transition énergétique. Les outils méthodologiques ont combiné la modélisation du type bottom-up et les techniques d'optimisation à travers les algorithmes de programmation linéaire. Nos résultats ont montré l'intérêt de la mise en place d'un cadre incitatif favorisant la transition énergétique. En termes de politique énergétique, nos résultats ont principalement deux implications. Dans un premier temps, ils ont soulevé l'importance d'une structure institutionnelle performante et fiable pour la bonne conduite des politiques de promotion des énergies propres. La fiabilité institutionnelle permet d'assurer une planification et une coordination optimale des différentes actions de mise en place des mécanismes incitatifs. Dans un second temps, nos résultats ont insisté sur la nécessité d'effectuer un arbitrage entre différentes politiques incitatives de promotion des énergies renouvelables dans les PED. Finalement dans l'ensemble des politiques incitatives simulées (renewable energy premium tariff, la taxe carbone, une subvention tarifaire de l'énergie propre et le renewable energy portfolio standard) nous avons montré qu'une attention particulière doit être prêtée aux effets redistributifs des politiques incitatives de promotion des énergies renouvelables.

Mot clés : Energies renouvelables ; pays en développement ; politiques incitatives ; modélisation énergétique

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Chapitre I : Introduction générale

Introduction

L'énergie est une composante essentielle dans le processus de développement économique d'une nation. Puisque dans un premier temps au niveau microéconomique l'accès aux services énergétiques permet aux ménages de satisfaire certains besoins de base tel que l'éclairage, le chauffage, la cuisson. Dans un second temps, au niveau macroéconomique la disponibilité d'énergie de qualité permet à certains secteurs d'accroitre leur compétitivité et, par conséquent, d'améliorer les conditions de croissance économique. Par exemple, aussi bien dans les secteurs industriel, agricole ou des services, l'accès aux services énergétiques est un « input » non négligeable permettant d'agir directement sur la production.

Cependant bien que l'énergie soit une composante essentielle au processus de développement, une grande partie des ressources énergétiques provient des combustibles fossiles, alors que ces dernières ont un impact négatif sur l'environnement. Par exemple The International Panel on Climate Change (IPCC, 2007) a dit il y'a quelques années que « *Currently, energy-related greenhouse gas (GHG) emission, mainly from fossil fuel combustion for heat supply, electricity generation and transport account for around 70% of the total emission including carbon dioxide, methane and some traces of nitrous oxide* ». Ce constat alarmant a soulevé une question majeure dans le domaine des sciences sociales. (1) comment continuer à fournir de l'énergie aux populations des pays en développement tout en minimisant la dégradation de l'environnement qui en découle ?

Pour répondre à cette question, différentes solutions ont été avancées. Dans un premier temps, une approche de management de la demande énergétique a été avancée, permettant aux pays soit de réduire leur consommation énergétique ou soit d'utiliser plus efficacement l'énergie. Cette approche, bien qu'importante, présente des limites puisque le niveau de consommation énergétique dans les pays en développement est déjà faible. Une politique visant à réduire la consommation énergétique ne peut être efficace que dans un cadre où l'accès aux services énergétiques n'est pas couvert de contrainte de disponibilité. Une seconde approche soulevée, dans un second temps, visait à introduire les technologies d'énergie renouvelable pouvant à la fois fournir de l'énergie tout en générant de faibles niveaux d'émissions environnementales.

Puisque, compte tenu des caractéristiques des pays en développement, il est supposé que ces technologies peuvent fournir un bon compromis à la fois de fourniture de services énergétiques et du respect de la qualité environnementale.

L'analyse de la transition énergétique s'articule autour de ce fondement. En effet l'analyse de la transition énergétique vise à étudier les conditions, moyens et conséquences de la modification des structures de production énergétique existantes basées sur les technologies fossiles vers celles intégrant les technologies propres qui sont plus respectueuses de la qualité de l'environnement. Par condition on entend les pré-requis techniques et institutionnels visant à favoriser la transition vers les énergies renouvelables. Les moyens et les conséquences s'articulent à la fois autour des instruments disponibles tant au niveau interne qu'externe et les conséquences résultant de la transition énergétique. Différentes approches sont souvent utilisées pour faire référence à la transition énergétique. Par exemple, la transition énergétique peut avoir une approche institutionnelle (Breukers, 2007 ; Thiam, 2010b), technologique (Kempf, 1998 ; IEA, 2008 ; Smith et al, 2010), sociologique (Shove and Walker, 2007), régulationniste (Jaffe et al, 1999) ou managériale (Rotman et al, 2001a ; Rotmans et al, 2001b ; Smith and Stirling, 2006 ; Verbong and Geels, 2007). Quelle que soit l'approche privilégiée, la transition énergétique analyse la manière de promouvoir une convergence vers un système socio-technique soutenable.

1: Théorie de la transition énergétique

La transition est définie comme « **a *social transformation processes in which such systems change structurally over an extended period of time*** » (Rotmans et al, 2001b). Deux raisons fondamentales justifient la nécessité de promouvoir la transition vers les énergies renouvelables dans les pays en développement. La première raison est la raison de sécurité énergétique et la seconde est liée aux questions de changement climatique. En effet, dans un grand nombre de pays en développement, l'architecture de l'offre énergétique est caractérisée par un faible taux d'accès aux services énergétiques, une dichotomisation entre les zones rurales et urbaines au niveau de l'accès à l'énergie et de faibles investissements dans le parc de production électrique. Cette cartographie de l'architecture énergétique renforce l'idée fondamentale consistant à devoir trouver des alternatives visant à assurer la sécurité énergétique. Dans un second temps, le recours aux technologies renouvelables permet d'atténuer le niveau d'émission générée lors de la production d'électricité. Dans ce contexte, différentes approches ont été avancées afin d'analyser la manière optimale de promouvoir une transition énergétique.

1.a : Approche institutionnelle de la transition énergétique

L'approche institutionnelle de la transition énergétique vise à analyser la structure institutionnelle favorisant la convergence vers un système socio-technico-économique soutenable. Elle s'appuie sur le rôle des différents acteurs (autorités publiques, consommateurs, producteurs, institutions étatiques, etc). Lorsqu'on se pose la question comment les institutions « The rules of the game in a society » (North, 1990) favoriseraient la transition énergétique dans les pays en développement ? Pour répondre à cette question, certaines analyses (Breukers, 2007 ; Thiam, 2010b) ont privilégié la référence à la nouvelle économie institutionnelle lorsque la transition énergétique se réfère à la diffusion des nouvelles technologies respectueuses de l'environnement. Puisque la nouvelle économie institutionnelle permet d'appréhender la relation entre différent acteurs et entre les institutions et les acteurs afin de promouvoir un changement de paradigme socio-technique (Thelen, 1999 ; Hall and Taylor, 1996).

Par ailleurs, l'analyse institutionnelle de la transition énergétique permet également de comprendre comment les sociétés au cours de leurs évolutions vont se réorganiser autour de certains acquis institutionnels. Cette réorganisation requiert la remise à niveau de certaines structures, la modification de certaines normes et orientation culturelle mais également la capacité à intégrer les nouvelles exigences socio-économiques dans la dynamique de la formation institutionnelle. Dans ce cas de figure, l'approche institutionnelle de la transition énergétique constitue un cadre d'analyse pertinent permettant de comprendre les enjeux des structures organisationnelles sur la convergence socio-technologique vers une dynamique plus soutenable. En assimilant la transition énergétique à une large diffusion des technologies plus respectueuses de l'environnement, Jacobson et Johnson (2000) ont montré le rôle des facteurs institutionnels sur la modification d'une structure organisationnelle présente vers une autre de nature plus soutenable. Ils avancent que les institutions - capturées par la fiabilité des différents programmes des gouvernements, le pouvoir organisationnel et politique d'une société - mais également les réseaux des différents acteurs ont un impact significatif sur le changement d'une structure technico-économique.

1.b : Approche technologique de la transition énergétique

L'approche technologique de la transition énergétique s'articule autour de deux orientations. Dans un premier temps, elle englobe les pré-requis technologiques permettant de favoriser une modification socio-technologique. Dans la littérature théorique ces pré-requis sont assimilés à la base scientifique et technologique d'une société permettant d'impacter sur une modification de paradigme technologique (Dosi et al, 1988 ; Lundvall, 1988 ; Nelson and Winter, 1982). Le changement de ces paradigmes technologiques se matérialise suite à une mobilisation des ressources scientifiques et technologiques afin de favoriser la dynamique d'une convergence socio-technologique. Dans un second temps, l'approche technologique de la transition énergétique se focalise sur les conditions techniques justifiant le « lock-in » de nouvelles technologies par une technologie plus mature. En effet, la théorie de la transition énergétique s'est longuement accentuée sur les sources de « lock-in » d'une technologie émergente face à une autre technologie plus mature. Par exemple, Unruh (2000) considère que le standard de l'architecture technologique joue un rôle important sur la matérialisation d'une situation de « lock-in ».

Par ailleurs la notion de « lock-in » renforce la structure de « *path-dependent* » dont les technologies émergentes sont confrontées. Dosi et al (1988) ainsi que Nelson et Winter (1982) ont, dans ce cadre, fourni une explication de la notion de « *path dependency* » par rapport aux stratégies de nouvelles technologies d'émerger sur un marché. L'approche technologique de la transition énergétique tente de fournir des changements techniques structurels nécessaires afin de faire converger un schéma socio-technologique existant vers un autre de nature plus soutenable.

1.c : Approche sociologique de la transition énergétique

L'approche sociologique de la transition énergétique vise quant à elle à analyser les raisons comportementales et culturelles entrainant la modification d'un régime socio-technologique existant. Cependant le concept sociologique de la transition prend ses racines dans l'analyse de la dynamique des populations. Transposé principalement dans le domaine énergétique par Kempf et al (2007), Martens et Rotmans (2005), Rotmans et Loorbach (2008), Loorbach et Rotmans (2010), la notion de transition énergétique se retrouve confrontée aux questions fondamentales du développement durable. En se basant sur les fondements sociologiques, il serait intéressant de s'interroger sur l'impact des comportements individuels et collectifs sur une modification de dynamiques socio-technologiques existantes basées sur les combustibles fossiles. Le phénomène de transition reste un phénomène procédural donc dynamique, son analyse requiert la compréhension des dynamiques sociologiques. Par exemple, certaines analyses (Walker and Shove, 2007) ont récemment montré le rôle des comportements sociologiques sur la transition vers un système plus « *Environmental-friendly* ». En avançant que «*The key idea is that change takes place through processes of co-evolution and mutual adaptation within and between different actors…… the systems in transition are typically distanced, even voyeuristics, making few claims about how individuals and organizations can, might or should act to affect the process in question or to steer trajectories towards pre-defined, normative goals* ». Par ailleurs Van der Kerkhof et al (2005) introduisent la notion de l'apprentissage dans le processus de transition sociologique. Ils dotent aux agents économiques certaines caractéristiques d'apprentissage leur permettant d'augmenter à la fois leurs capitaux cognitif et technique permettant d'optimiser leur choix dans un processus dynamique.

1.d : Approche régulationniste de la transition énergétique

Cette approche s'articule autour des courants de l'économie de l'environnement et du changement technique. Elle vise à analyser l'impact des politiques de régulation environnementales et technologiques promouvant la transition énergétique. Dans ce cas de figure la transition énergétique se résumerait aux mécanismes de régulation environnementales et technologiques visant à promouvoir un système socio-économique soutenable.

Ces mécanismes ont deux objectifs. Dans un premier temps ils visent à réduire les externalités environnementales provenant du système socio-économique non soutenable (secteur des combustibles fossiles). Dans ce cadre, différentes politiques publiques sont privilégiées. Ces politiques publiques peuvent variées entre les instruments économiques (Jaffe et al, 1999) aux instruments de cap-and-trade (Menanteau et al, 2003). Les instruments économiques peuvent inclure des politiques fiscales, de subvention et de mise en place des permis négociables. Les instruments de cap-and-trade visent quant-à elles à promouvoir la transition énergétique en privilégiant une approche bornée par les quantités. Dans un second temps, les mécanismes de régulation technologique promouvant la transition énergétique peuvent utiliser – comme cela a été le cas depuis longtemps - une politique de « demand pull » mais également de « technologypush ». En effet dans la littérature théorique il est admis qu'aussi bien l'amélioration des conditions de marché que des caractéristiques technologiques peuvent influencer le changement technologique. Dans le domaine énergétique des conditions de marché peuvent être la résultante d'une modification des prix des énergies fossiles, alors que les caractéristiques technologiques s'assimilent à l'apparition de nouvelles formes de paradigme technologiques favorisant les technologies propres (i.e niche, invasion spatiale).

1.e : Approche managériale de la transition énergétique

L'approche managériale de la transition énergétique est la plus répandue mais également la plus analysée dans la théorie de la transition énergétique. Les pionniers peuvent être considérés comme étant les disciples de l'école Hollandaise (Rotmans et al, 2001a ; Kemp, 1997). Lorsqu'on considère la transition énergétique comme un phénomène dynamique (Rotmans et al, 2001b), nous pouvons supposer qu'elle suit une courbe en S et qu'elle est constituée de cinq phases (figure 1). De la période de pré-développement à la période de stabilisation, une combinaison institutionnelle, technologique, sociologique et régulationniste sera couplée avec une approche managériale afin de créer les conditions favorisant la transition énergétique. Par ailleurs, l'approche managériale de la transition énergétique s'est démarquée des autres approches, en proposant un cadre analytique clair à travers lequel la transition énergétique pourrait se focaliser. Par exemple, elle prône une approche « multi-level » incluant les différentes caractéristiques des conditions techniques mais également institutionnelles. L'implication « multi-level » permettrait de combiner une dimension micro - meso – macro level (figure 2). La dimension micro-level permettrait par exemple d'identifier à court et à moyen terme des niches de marché où la transition énergétique sera privilégiée. Ces niches pourraient intégrer de nouvelles technologies moins polluantes mais également elles pourraient s'assimiler à de nouvelles normes et législations, nouvelles formes d'organisation ou même de nouveaux projets. Par ailleurs, en accumulant les niches, on génère différents régimes (méso-level). Ces régimes générés contribuent au renforcement des capacités internes promouvant la transition énergétique. En plus, ces régimes une fois accumulés faciliteront le « overlapping » des différents secteurs pour une transition plus soutenable. Une fois ces régimes accumulés, la transition se diffuse dans un cadre spatial permettant une large distribution de ses impacts (macro-level). Au delà de cette imbrication dynamique complexe, il est aussi important de souligner que la transition est présentée comme un phénomène incorporant des incertitudes durant les différentes phases de sa réalisation.

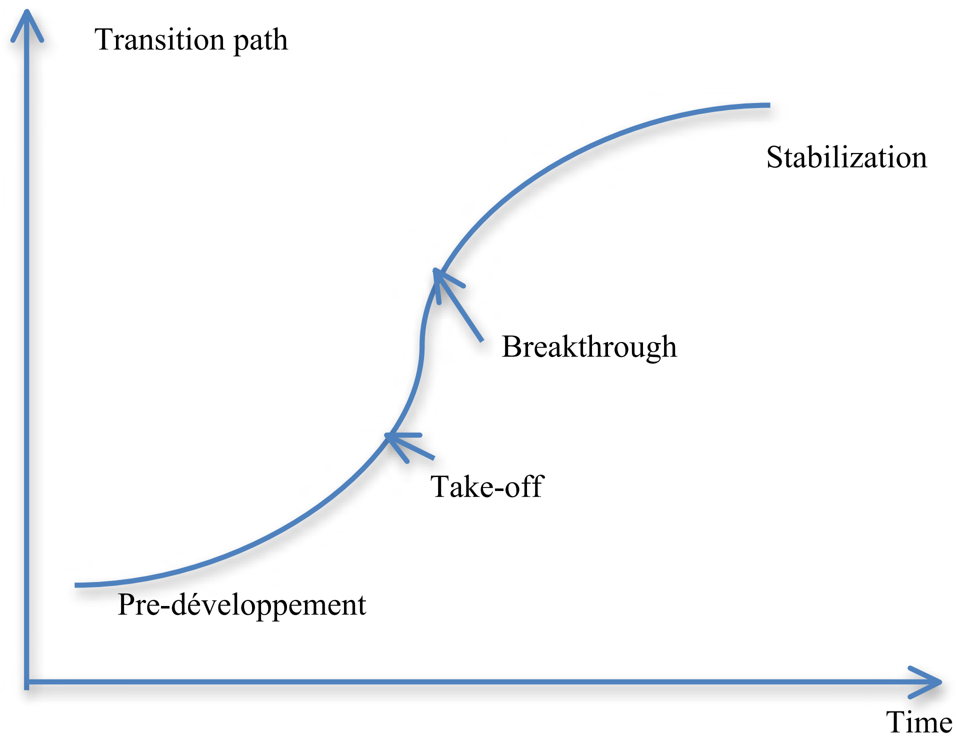

Figure 1 : étapes de la transition énergétique

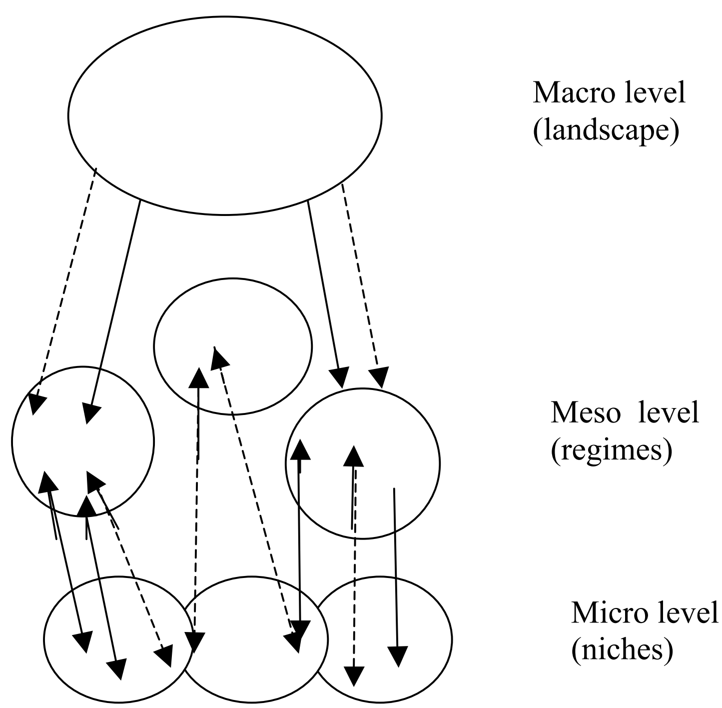

Figure 2 : Schéma de transition énergétique

2 : Limites des approches existantes et nécessité de considérer d'avantage les spécificités des pays en développement.

Deux constats peuvent être faits par rapport à la littérature existante sur la transition énergétique. Dans un premier temps, l'analyse de la transition énergétique tire quasi - entièrement ses fondements analytiques dans les pays développés. Cette origine épistémologique rend cette analyse unidirectionnelle dans le sens où les modifications institutionnelles, technologiques et managériale sont celles basées sur une dynamique dotée de certaines caractéristiques énergétiques. Par exemple dans les pays industrialisés, les caractéristiques du secteur énergétique sont très largement différentes de celles des pays en développement. Par exemple, pendant que dans les pays développés l'accès aux services énergétiques est un acquis, dans les pays en développement une grande partie de la population n'a pas accès aux services énergétiques. Par exemple, IEA (1998) avance que 1.6 millions de personnes dans le monde n'ont pas accès aux services énergétiques, et la majeure partie de cet échantillon se trouve localisée dans les pays en développement. En plus, la majeure partie de cet échantillon se trouvant dans les pays en développement est localisée dans les zones rurales et éloignées (enclavées) où l'accès aux services énergétiques via les méthodes classiques de distribution centralisées est financièrement difficile. Dans ce cas de figure, l'analyse de la transition énergétique se doit d'intégrer cette caractéristique spécifique des pays en développement. Puisqu'en prenant en compte la dichotomisation des niveaux d'accès aux services énergétiques, l'analyse de la transition énergétique permettrait de faire converger d'une manière plus homogène les PED vers un système socio-technologique soutenable.

Dans un second cas, un constat peut être fait assez facilement sur le manque (plutôt la faiblesse) des analyses portant sur les instruments favorisant la transition énergétique dans les pays en développement en intégrant d'avantage leurs caractéristiques. La quasi-totalité des instruments mis en œuvre pour promouvoir un système socio-technologique soutenable trouve leurs fondements empiriques dans les pays industrialisés, puisqu'ils sont directement soumis à travers le protocole de Kyoto à la réduction de leurs niveaux d'émission de carbone dans les années à venir. Cette obligation se justifie à la fois par leurs responsabilités historiques par rapport au réchauffement planétaire mais également par leur besoin de crédibilités lors des négociations internationales sur les enjeux du changement climatique. Dans ce cadre, différents instruments ont été mis en œuvre afin de faciliter la transition énergétique. Généralement ces instruments ont deux effets. Dans un premier temps, ils envisagent de réduire le niveau d'émission globale des pays industrialisés en facilitant le « reaching-up » des pays en développement à travers des instruments de marché comme le « Clean Development Mechanisms » (CDM) ou la « Joint Implementation » (JI). Dans un second temps, les instruments peuvent également directement agir à l'intérieur des pays industrialisés afin de réduire leur niveau de pollution à l'interne à travers une réorientation ou une remise à niveau de choix de politique industrielle. Par exemple aussi bien qu'aux USA qu'à l'intérieur des Etats membres de la Commission Européenne, des mesures incitatives ont été prises dans une logique de promouvoir la transition énergétique via une facilitation de la diffusion des technologies propres dans le processus de génération d'électricité.

A partir de ces constats, deux orientations seront proposées, les quelles constitueront le corpus de notre travail de thése. Dans un premier temps, nous avançons l'idée que la transition vers les énergies renouvelables dans les PED doit combiner à la fois des approches décentralisées (pour prendre en compte les caractéristiques spatiales des zones enclavées) et centralisées (afin de mettre les PED dans une dynamique de convergence socio-technologique plus soutenable). Cette orientation peut être considérée comme étant le nouveau modèle de transition dans les pays en développement. Car, d'un coté, elle permet de répondre à la question (1) posée en haut, à savoir comment continuer à fournir de l'énergie aux populations des pays en développement tout en minimisant la dégradation de l'environnement qui en découle ? Dans un second temps, l'avantage de ce schéma permettrait aux zones enclavées d'accéder aux services énergétiques mais également d'améliorer leurs conditions de vie à travers l'accroissement des activités créatrices de revenu découlant de l'accès aux services énergétiques. En plus, promouvoir la transition énergétique via la décentralisation énergétique (off-grid) permettrait aux PED d'épargner les coûts de transports des réseaux de distribution électrique puisque les services énergétiques sont produits aux points de consommation.

La seconde orientation vise à promouvoir une transition vers les énergies renouvelables du type « Bottom-up » c'est-à-dire permettant aux PED d'être des acteurs de leurs propres modifications socio-technologiques. En effet, rares sont les PED qui prônent la transition vers les énergies propres à travers la mise en place des politiques tarifaires ou publiques. Alors que la notion de soutenabilité requiert une implication des sociétés à travers les choix de politiques publiques, nous analysons dans ce cas une possible implication des PED à travers la mise en place des politiques publiques promouvant la transition vers les énergies renouvelables. Dans ce cas, nous différentions entre les politiques visant à promouvoir la transition à la fois vers les zones éloignées mais également vers les zones urbaines.

3: Objectif de la thèse et questions de recherche

3.a : Objectif de la thése

L'objectif de cette thèse est d'analyser l'apport des énergies renouvelables à la transition énergétique dans les pays en développement. Afin de mener des analyses fines, nous allons nous focaliser sur deux pays en développement de natures opposées à savoir ***le Sénégal et l'Afrique du Sud***. Le Sénégal est un pays pauvre très endetté (PPTE) alors que l'Afrique du Sud fait partie du groupe des pays BRICS (Brésil, Russie, Inde, Chine et Afrique du Sud). Ces groupes de pays sont à eux seul responsables de plus de 80% de la croissance économique mondiale. Le choix des pays aussi différents pour analyser l'apport des énergies renouvelables à la transition énergétique se justifie à deux niveaux. Dans un premier niveau, notre objectif est d'analyser la transition vers les énergies renouvelables dans des pays avec des structures technologiques, industrielles, énergétiques et institutionnelles différentes. Cette différence nous permettra d'ajuster le choix des politiques incitatives de promotion des énergies renouvelables et de voir l'impact de la spécificité de chaque nation sur la dynamique de la modification socio-technologique. Dans un second temps, prendre des PED aux caractéristiques aussi différentes permettrait d'ajuster le choix des instruments du type « Bottom-up » par pays. Par exemple, dans notre thése, certains instruments se verront être plus adéquats compte tenu de la structure de l'offre énergétique en Afrique du Sud qu'au Sénégal. Par ailleurs, malgré leurs différences en termes économiques, technologiques et institutionnelles, les deux pays ont un dénominateur commun en termes de promotion de la transition énergétique à partir des technologies propres. En effet, les deux pays restent très actifs quant à l'idée de promouvoir les technologies renouvelables. De nombreux programmes sont lancés aussi bien au Sénégal qu'en Afrique du Sud pour promouvoir la transition énergétique. Par exemple, au Sénégal nous pouvons faire référence au projet Microgrids, financé par l'Union Européenne visant à promouvoir les énergies propres dans trois zones rurales éloignées (Thies, Diourbel et Fatick). Dans le cas de l'Afrique du Sud, plusieurs initiatives ont été avancées à travers des mécanismes de marché (CDM), permettant de faciliter la transition énergétique.

3.b : Questions de recherche

L'objectif de la thèse est d'analyser l'apport des énergies renouvelables à la transition énergétique au Sénégal et en Afrique du Sud. Dans ce cadre quatre questions de recherche seront traitées.

Question 1 : Quels sont les déterminants de la transition vers les énergies renouvelables dans les PED ? Quelles structures de gouvernance pourraient faciliter leur adoption par les PED?

Question 2 : Comment les énergies renouvelables peuvent-elles contribuer à renforcer la transition énergétique dans les zones rurales éloignées au Sénégal et en Afrique du Sud (2a)? Comment de telles approches peuvent-elles être financées et quelles en seront leurs conséquences économiques et sociales (2b) ?

Question 3 : Comment les énergies renouvelables peuvent-elles faciliter la transition socio-technologique dans le secteur de la production électrique au Sénégal et en Afrique du Sud?

Question 4 : Quelles sont les conséquences économiques, environnementales et sociales de la mise en place d'un cadre « Bottom-up » visant à impliquer le Sénégal et l'Afrique du Sud dans le processus de transition énergétique ?

4 : méthodologie de la thèse

Bien que ses fondements soient basés sur l'analyse économique, cette thèse privilégie une approche interdisciplinaire. Nous combinons les approches analytiques, économiques et d'ingénierie afin d'analyser l'apport des énergies renouvelables sur la transition énergétique au Sénégal et en Afrique du Sud. Par ailleurs, cette thèse fournit un cadre scientifique permettant la prise de décision par les « energy policy-makers » dans le domaine de la promotion des énergies propres. Dans le domaine des sciences économiques, notre travail s'articule autour de l'économie de l'énergie qui est, par nature, un domaine interdisciplinaire car imbriquant différentes parties de la science économique.

4a : approche analytique

L'approche analytique développée dans cette thèse envisage la conceptualisation des éléments favorisant la transition vers les énergies renouvelables. Considérant explicitement la nature de ces éléments nous proposons une analyse approfondie des interactions entre la nature des différents éléments enfin de promouvoir la transition vers les énergies propres. Ces éléments en question sont basés sur la dynamique technologique des technologies propres et leurs caractéristiques durant leur processus de promotion.

4b : approche économique

L'approche économique consiste quant à elle à utiliser des fondements microéconomiques pour traiter les questions relatives aux dynamiques de la transition vers les énergies renouvelables. Se plaçant sous la coupe de l'approche néoclassique, nous avons supposé que les producteurs et les consommateurs maximisent leur bien-être en maximisant respectivement leur fonction de profit et d'utilité. Nous avons également utilisée la notion de surplus des consommateurs et des producteurs pour analyser l'impact de la transition énergétique sur le bien-être global.

4c : approche d'ingénieurie

Dans la thèse l'approche d'ingénierie s'articule autour de deux points. Dans un premier point, l'analyse du cycle de vie a été menée en vue de voir le bien fondé de la transition vers les énergies renouvelables. Ensuite, dans un second temps, nous avons utilisé le modèle de simulation du type « Bottom-up », PowerPlan développé par le « Centre for Energy and Environmental Sciences » de l'université de Groningen, IVEM. Ce modèle du type d'ingénierie permet de répondre à certaines questions comme « What if », permettant de simuler les effets de la transition vers les énergies renouvelables dans le secteur électrique.

5 : Source de données

Cette thèse a utilisé différentes sources de données pour analyser l'apport des énergies renouvelables à la transition énergétique au Sénégal et en Afrique du Sud. Nous avons beaucoup utilisé les données des technologies énergétiques fournies par les statistiques locales des pays ciblés. Par exemple, pour le cas du Sénégal, nous avons utilisé les statistiques du Système d'Information Energétique (SIE), de l'Agence Sénégalaise d'Electrification Rurale (ASER), de la Société Nationale d'Electricité du Sénégal (SENELEC). Pour les cas empiriques des technologies énergétiques de l'Afrique du Sud, nous avons utilisé les rapports produits par le « Energy Research Centre, ERC » de l'Université de Cap Town, du département de l'énergie du « Council for Scientific and Industrial Research, CSIR », et du « Department of Mineral Energy , DME». Le reste des données liées aux caractéristiques technico-économiques des technologies énergétiques a été fourni par la base de données de l'Agence Internationale de l'Energie (AIE). Les données des ressources énergétiques renouvelables sont également fournies par les statistiques locales (Agence Nationale de la météorologique du Sénégal et CSIR pour le cas de l'Afrique du Sud). Cependant, comme la majeure partie des thèses en économie appliquée, les difficultés liées aux collectes de données ont été contournées par une « proxisation » des données nationales par les données existantes sur le marché international des technologies énergétiques. Cette contrainte n'a pas pour autant biaisée nos résultats puisque les technologies énergétiques présentent beaucoup plus de similitudes entre elles que ne le sont d'autres types de technologies.

6 : structure de la thèse

La thèse se structure sous forme d'articles. Nous avons tenu à répondre aux différentes questions posées (Q1 – Q4) à travers des articles. L'ensemble des articles de la thèse ont soit fait l'objet de publication ou soit soumis dans des revues à comité de lecture, et sont actuellement en cours de révision. Au delà de l'introduction et de la conclusion, cette thèse est constituée de cinq chapitres.

Le chapitre 2 de la thèse analyse les déterminants de la transition vers les énergies renouvelables dans les PED et propose une structure de gouvernance pouvant faciliter leur adoption (Q1). Ce chapitre s'est donné une dimension assez théorique, en balayant les contraintes technologiques, de marchés et institutionnelles entravant la promotion des énergies renouvelables dans les PED. Ce chapitre propose également une approche de gouvernance de la transition vers les énergies propres. Dans ce cadre, il identifie une articulation séquentielle entre les pouvoirs publics, les entrepreneurs privés et les « stakeholders » en vue de stimuler la promotion des énergies renouvelables. Ce chapitre a fait l'objet d'une publication à comité de lecture comme chapitre d'ouvrage dans Morena J. Acosta (ed.) : *Advances in Energy Research. Volume 9*, Nova Publishers, ISBN: 978-1-61470-485-0 . Une version plus affinée de ce chapitre est est acceptée dans la revue à comité de lecture *International. Journal of Technology, Policy and Management*

Le chapitre 3 de la thèse analyse l'apport des énergies renouvelables à la transition énergétique sous une approche décentralisée (off-grid) (Q2a). En se basant sur le cas du Sénégal, nous montrons la compétitivité-coût de l'option décentralisée des technologies propres dans les zones isolées. Ce papier s'inscrit dans le cadre du projet Microgrids financé par la Commission Européenne visant à promouvoir les technologies propres dans les pays en développement. La méthodologie retenue dans ce papier est l'analyse du cycle de vie. Elle consiste à déterminer le « Levelized-Electricity-Cost » de différentes technologies de production électrique. Ce chapitre a été publié à la revue à comité de lecture *Renewable Energy*

Le chapitre 4 est le prolongement direct du chapitre 3 puisqu'il analyse les mécanismes de financement de la transition vers les énergies renouvelables selon l'option décentralisée (Q2b). L'application empirique s'applique à nouveau sur le cas du Sénégal. L'instrument de financement simulé est le « *renewable energy premium tariff* ». Ce dernier est supposé encourager la promotion des énergies renouvelables dans les zones rurales enclavées dans les pays en développement (EC, 2008). La méthodologie retenue combine les techniques de programmation linéaire et l'approche de la Valeur Ajoutée Nette (VAN). Ce chapitre est publié dans la revue à comité de lecture *Energy Policy*

Le chapitre 5 se place également dans la continuité des chapitres précédents puisqu'il envisage la transition vers les énergies renouvelables non plus selon une approche décentralisée mais selon l'optique centralisée (Q3). L'hypothèse sous-jacente est – comme énoncée plus haut – que la transition vers les énergies renouvelables aussi bien en Afrique du Sud qu'au Sénégal devrait combiner une dynamique décentralisée et centralisée. Cette combinaison des dynamiques trouve sa légitimité dans la spécificité des structures spatiales des deux pays dans les quels la population est directement subdivisée entre zones rurales et urbaines. Dans ce schéma, l'axe d'intervention visant à promouvoir la promotion des énergies renouvelables au Sénégal et en Afrique du Sud doit être, par conséquent, de nature bidirectionnelle envers les zones enclavées pour le court et le moyen terme et les zones urbaines pour le long terme. Ce chapitre analyse la transition dans le secteur électrique des deux pays cibles. Dans ce cadre il permet de répondre à la question : comment les énergies renouvelables peuvent-elles faciliter la transition socio-technologique dans le secteur de la production électrique au Sénégal et en Afrique du Sud ? (Q3). La méthodologie retenue est le modèle PowerPlan du type « Bottom-up ». Ce chapitre est accepté dans la revue à comité de lecture *Applied Energy*.

Le chapitre 6 de la thèse adopte une vision assez imbriquée des chapitres précédents. Il aborde la transition vers les énergies renouvelables dans une approche de politique publique. L'intérêt d'aborder une telle dynamique consiste – comme indiqué plus haut – pour les PED de prendre les initiatives, à travers la mise en place des politiques publiques internes, consistant à promouvoir les technologies propres. Le cas empirique s'applique au cas de l'Afrique du Sud puisque ce dernier, comparé au Sénégal, dispose d'un meilleur potentiel économique et institutionnel permettant de mettre en œuvre des politiques publiques incitant à la promotion des technologies propres. Dans ce cadre nous analysons les conséquences économiques, environnementales et sociales de la mise en place d'un cadre « endogéne » visant à impliquer l'Afrique du Sud dans le processus de transition énergétique (Q4). Par ailleurs, promouvoir les technologies propres à travers la mise en place des politiques publiques internes permettrait à l'Afrique du Sud de compléter les moyens disponibles au niveau international promouvant les technologies propres dans les PED. Ce chapitre est soumis dans la revue à comité de lecture *Energy Policy.*

Chap 2: The constraints in managing a transition towards clean energy technologies in developing nations: Reflections on energy governance and alternative policy options[1]

Abstract

Although the impacts of renewable energy utilization on the diversification of energy supplies and the mitigation of climate change in developing nations are globally recognized, little is known about which organizational framework renewable technologies could be strategically and durably deployed in developing nations. To bridge this gap, this paper aims to investigate the conditions and schedules that would stimulate the diffusion of environmental-friendly technologies in developing nations. In doing so, we first index theoretical factors preventing deployment of renewable technologies. After having identified these factors, we provide a framework of energy governance and strategic energy policy actions through which the diffusion of renewable technologies in developing nations could be based. We argue that stimulating an adoption of renewable technologies in developing nations requires a combination of actions overlapping technological, market, and institutional aspects. Moreover in order to generate a sustainable electricity production path, energy policy-makers in developing nations should embed a promotion of renewable technologies in a national energy policy agenda. This paper also seeks

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[1] [1] This chapter is a slightly adapted version of Djiby Racine Thiam, 2011. Promoting Transition towards Free Carbon Technologies in Developing Nations: Overcoming Existing Theoretical Barriers through Energy Governance Strategies in Morena J. Acosta (ed.) : *Advances in Energy Research. Volume 9* , Nova Publishers, ISBN: 978-1-61470-485-0 and of Djiby-Racine Thiam; Moll, H, "The constraints in managing a transition towards clean energy technologies in developing nations: Reflections on energy governance and alternative policy options" Forthcoming in International Journal of Technology, Policy and Management.

to provide a conceptual framework through which the objective of promoting deployment of clean technologies in developing nations could be based.

JEL: O33; O38; Q58
Keywords: renewable technology, developing nations, energy governance, energy transition

2. 1: Introduction

The use of renewable technologies has received widespread interest in many countries. Many nations - both developed and developing - have set up incentive mechanisms in order to increase the diffusion of renewable technologies throughout their energy portfolio. The reasons behind this increasing interest in clean[2] technologies can be summarized in three points. First, the use of renewable technologies improves the environmental quality through a reduction of greenhouse gas (GHG) emissions during the electricity generation phase (World Bank 2006; IEA, 2002; Thiam, 2010; Bhattacharyya, 2007). GHG emissions have important impacts on climate change, therefore their increase is widely considered as a threat to modern societies. The threat of climate change in terms of economic, ecological and social impacts urges many countries to find alternative paths for providing electricity. Second, using renewable technologies also provides positive economic impacts. The economic reason for promoting renewable technologies is their ability to save fuel costs and to lower operating and maintenance costs (IAE, 2002). Renewable energy generation does not require fossil fuels for its operation,[3] so fossil fuel price variations affect neither the quantity of electricity produced nor the performance of the energy system. Finally, the use of renewable technologies also presents positive social impacts which are more relevant to developing countries compared to industrialized ones. In many developing nations,

[2] The term clean technologies uses sometimes through the chapter refers to the renewable technologies

[3] However it is important to acknowledge that wind energy does require fossil fuels to start the turbines.

remote locations do not have access to energy services (Thiam, 2010; Bhattacharyya, 2007; Karekezi et al., 2003). The promotion of renewable energy offers a good alternative to providing energy services through decentralized processes. The decentralized process has important social impacts while it facilitates social connection through night time length extension. Moreover the decentralized process increases appliance availability such as TV, radio, network communication in remote communities in developing nations.

In this context, promoting deployment of renewable technologies is assumed to be a part of a strategy of sustainable development as it includes economic, environmental and social dimensions (Bhattacharya, 2010). However, although the importance of clean technologies on the economic-ecological-social path remains well recognized, it is important to highlight the fact that most of the incentive mechanisms promoting the diffusion of renewable technologies are focused on industrialized nations. Many papers have investigated the impacts of financial incentive mechanisms (Menanteau et al., 2003; Lauber, 2004; Meyer, 2003; Hvelplund, 2001; Mitchell, 1994; Neuhoff, 2005) and organizational governance structure (Kern et al 2008; smith et al, 2010) promoting the diffusion of renewable technologies in industrialized nations. They all reach one main conclusion: in an earlier stage of their development renewable technologies need public support in order to get to market (Menanteau et al, 2003; Mitchell, 1994; Neuhoff, 2005; Banales-Lopez et al, 2002).

The objective of this paper is to overcome this limitation by proposing alternatives through which renewable technologies could be stimulated in developing nations as well. We provide an analytical approach in which a target to promote deployment of renewable technologies in developing nations follows two main steps. In the first step, we analyse conditions of successes of the diffusion of renewable technology by providing potential factors constraining the deployment of clean technologies in developing nations. Indeed we identify the existing theoretical barriers that are preventing the diffusion of renewable technologies in developing nations. Based on these theoretical barriers, we explain why renewable technologies are still facing a framework of lock-in compared to fossil-fuel technologies. In the second step, to overcome these existing barriers, we provide a set of energy governance[4] behaviors and sustainable energy transition[5] strategies through which the promotion of renewable technologies can be based in developing nations.

The analysis of the governance for a transition towards a sustainable energy generation presents, in our point of view, some interesting aspects. On the one hand, it provides a conceptual framework through which policies promoting diffusions of clean technologies could be assimilated as entire components of a national energy policy. Including policies promoting diffusion of renewable energy as components of energy policies in developing nations is a requirement in order to create and to sustain a renewable technology market. While this sustainability of the renewable technology market is also required in order to increase investment opportunities and to secure its dynamic of the long-term return. Such structures securing investment returns can only be achieved under the harmonization of national energy policies and once considering clean technology deployment as a component of the entire energy policy. On the other hand, in developing nations, providing proper energy governance requires the re-linking of energy and development policies. Since long times in developing nations policies promoting deployment of renewable technologies were disconnected to the national energy policy agenda (UNDP, 2010). Most deployments of renewable technologies were carried out by development

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[4] We undertand that the concept of "energy governance" is a large term and can cover different meaningfuls in the theoretical path. In this paper "energy governance" requires a coordination effort and changes among many different actors, institutions and artefacts (Unruh, 2002; Elzen et al., 2004; Smith et al., 2006) for the success of any energy planning scheme.

[5] The energy transition reflects the change in energy resource consumption. For example the substitution of biomass energy by wind or solar PV energy

agencies through a poverty reduction agenda. This situation has let few opportunities to national energy policy-makers to address long-term renewable energy deployment policies. As a result, most of the investments raised for renewable energy deployment fail because of a lack of coordinated efforts and involvement by energy policy-makers.

The paper is organized as follows. In section 2, we identify existing theoretical barriers preventing the rapid diffusion of renewable technologies in the market. After having explained conditions maintaining renewable technologies in a lock-in scheme compared to fossil fuels technologies in section 3, we provide in section 4 a structure of energy governance stimulating the transition towards a clean-technology path in developing nations. In order to investigate the issue deeply, we present in section 5 specific energy policy strategies with which energy policy-makers in developing nations can refer in order to increase the amount of renewable technology in the energy balance. Finally, in the last section 6, we provide some summarizing conclusions.

Section 2.2: assessment of theoretical barriers of renewable technology diffusion

The theoretical factors affecting the diffusion of renewable technologies in developing countries can be summarized in three points: technical, market and institutional factors.

2. 2. 1 : Technical factors

The technical factors explain the technical evolution of renewable technology devices and show explanatory variables emphasizing why new technology remains expensive or gets cheaper over time. This issue is addressed through an analysis of the experience curve of a technology. The experience curve relates the reduction of the unit cost of the technology to the increment of the cumulated production (Arrow, 1962; Wright, 1936). There are three types of experience curves (table 1) when one consider renewable technologies:

Table 1: types of experiences curves

Types of curve	Explanatory variables	Explained variables
A	Cumulated capacity installed or produced (KW)	Unit cost of capacity
B	Cumulated number of KWh produced	Price of electricity
C	Cumulated capacity installed or produced (KW)	Price of electricity

Source: adapted from source Junginger et al, (2005)

Experience curve related of the unit cost of the technology to the (a) incremental of the cumulative capacity installed or produced (b) the electricity price reduction per unit of the cumulative amount of electricity generated (c) and the electricity price reduction per unit of the cumulative capacity installed or produced. All these three forms of experience curves provide a learning process effect. Furthermore, in the framework of experience curves, the decline of production costs is expressed through a progress ratio.

2. 2. 1. a: Theory of experience curve

The theory of the experience curve[6] expresses the unit cost of the technology to the cumulated production (cumulated in terms of capacity installed or output generated). A specific characteristic of an experience curve is that the cost decreases by a constant percentage with each doubling of the total number of units produced. Generally, the curve is expressed as:

$$C_{CUM} = C_0 . CUM^{\alpha} \qquad (1)$$

$C_{CUM} =$ The cost per unit as a function of output

[6] This theory has been originally observed in the field of Aeronautic by Wright (1936) before the second world war. The idea has been translated in Economics by Kenneth Arrow since 1962 in his seminal paper "The Economic implications of learning-by-doing" published in "Review of Economic Studies" 29, pp 155-173

CUM = The cumulative production over time

C_0 : Cost of the first unit produced

α = Elasticity of united cost with respect to (CUM)

The term α defines the constant elasticity unit at which the unit cost reduction takes place. The reduction of the unit cost is carried out through the progress ratio represented in the following equation.

$$PR = 2^{-\alpha} \quad (2)$$

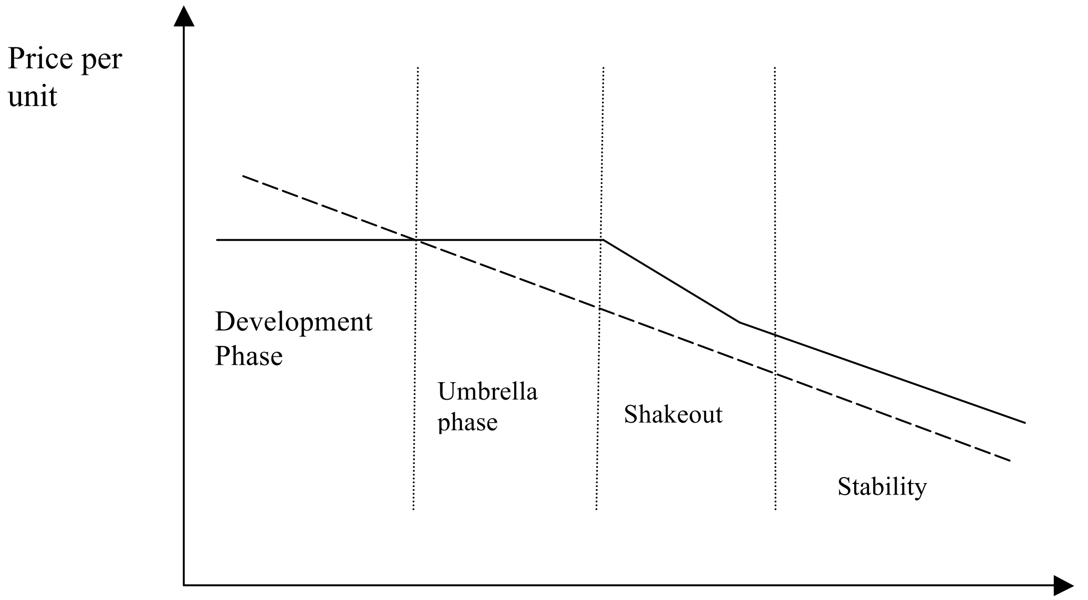
$$LR = 1- PR \quad (3)$$

Different studies have attempted to determine the progress ratio of renewable technologies (Neij, 2008; IEA, 2005; Junginger et al, 2005). For example a progress ratio of 73% means that costs are reduced to 73% from their previous values. In other terms in each doubling of cumulative production the cost is reduced by 27% (complement of 73%).

However, in reality to evaluate the learning curve empirically - due to the lack of reliable data on renewable technologies - the experience curve uses electricity prices (IEA, 2005). In fact the learning curve explains a fall in electricity prices according to the cumulative installed capacity of environmentally friendly technologies or the amount of renewable electricity generated. In this framework, it is interesting to note that the experience curve approach contains some shortcomings. The relation between the price of clean electricity and renewable technology capacities installed is tangible only if one considers the characteristics of the energy market. Indeed, the electricity price movement can be driven by other non-costs factors as well (Jamil and Ahmad, 2010; Rathmann, 2007). For example, in a market in which competition prevails, the marginal cost tariff is performed contrary to the market in which the electricity sector follows a vertically integrated structure[7]. In a vertically integrated market structure, prices are not entirely anchored to the evolution of costs because there are different strategic factors influencing their dynamics. These strategic factors can be driven, for example, by social impacts that access to energy provides to local populations. This justifies the fact that in many developing nations, the energy service is managed under a social purpose. The access to electricity is seen as a development driver, enabling the improvement of living conditions for many people in different areas. In this context, anchoring the evolution of electricity price to the technological cost can create some social inconveniences. The second shortcoming of the experience curve is related to conditions of technology implementation in a market. In fact for a new renewable technology, the price evolution does not immediately follow the evolution of costs involved. For a manufacturer, for example, bringing a technology into the market requires different strategies through which a benchmark market is created. For example, the Boston Consulting Group (BCG) identifies the relationship between the technology price and the cost evolution in four stages namely the development, umbrella price, shakeout and price stability phases (figure 1).

[7] The vertical integration is a characteristic of market through which competion is not performed. The most well known type of a structure of a vertical integration is the case of the state-owner monopole enterprise in a market.

Figure 1: relationship between costs and prices during the introduction of news technologies

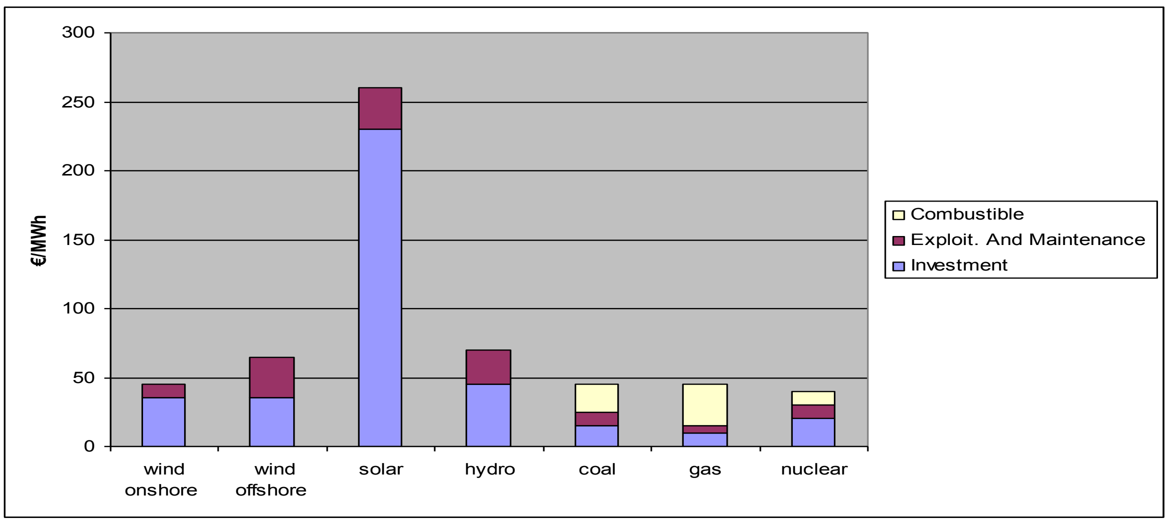


Source: Junginger (2005)

During the development phase, the objective of the manufacturer is to create a benchmark market within which prices are lower than technological costs. The loss in terms of (cost-price) is recovered through an effect of scale while the increase in production decreases costs, therefore reduces differences between costs and prices. During the umbrella framework, the manufacturer cumulates an increase of unit price coupled with advantages given by the effect of scale in order reabsorb the marginal profit lost during the development phase. However, as the structure of the benchmark market becomes attractive for potential investors to enter in the market, the first manufacturer - even if he (she) has a dominant position – reduces the technology price in order to keep market power against new competitors (shakeout phase). This behaviour results in the exclusion of competitors into the renewable technologies markets.

Although the progress ratio of renewable technologies is coming down during the past years, many clean technologies are still more expensive than fossil-fuel technologies. Fossil-fuel technologies have reached a higher level of technological maturity and a deeper learning-process effect. This technical limitation is considered as an important theoretical blocking factor for the diffusion of renewable technologies while their adoption still remains highly financial capital-intensive compared to fossil-fuel technologies (Menanteau et al, 2003; Junginger et al, 2005). Figure 2 shows the evolution of the marginal costs of different renewables compared to fossil-fuel technologies. In figure 2 there is no doubt that the investment cost of renewable technologies remains higher than classical electricity generating technologies. But their advantage is they don't required combustible costs.

Figure 2 : long term marginal costs of different electricity generating technologies (€/MWh)



Sources: adapted from Bordier (2008)

2. 2.2 Market factors

Beyond technological factors, the dynamic of an existing energy market could constrain large adoption of new technologies. The market factors preventing large diffusion of free carbon technologies in developing nations can take two forms: endogenous competitions between electricity generating technologies within the market and the non internalization of environmental externalities from fossil-fuel electricity generating technologies. To explore the first market blocking factor, we refer to the work of Arthur (1988; 1989). Under this literature, the adoption (diffusion) of new technologies is highly dependent on its previous adoption path by first adopters (earlier consumers). Moreover technologies become more attractive, developed, widespread and useful the more they are adopted. Since potential adopters evolve in a connected network, the choice of the first technological adopter influences the decision of following adopters. In this context once a technology (B) is chosen again a (D) one, (B) has a high probability to remain dominant compared to (D) in the market. Indeed all coming adopters will choose (B) which is considered as less risky than (D) because it is more known and familiar. However, one prerequisite is behind Arthur's technology competition analysis: the increasing returns of adoption (IRA) providing an expansion of the technological network in the market and strengthening its probability of adoption by the next coming adopters.

The analysis of the competition between technologies identifies five mechanisms through which IRAs take place: learning-by-searching (Rosenberg, 1982), learning by doing (Arrow, 1962), availability of technological spillovers (Katz et Shapiro, 1985), increasing information networking (Cowan, 1988) and technological interrelation (David, 1996).

- *Learning-by-searching and learning-by-doing*

Learning-by-doing and/or learning-by-searching analyse improvement of technological capabilities through increased experience of using a technology. These effects can have impacts either on cost reduction of selected devices and/or reliability acquired within the technology development.

- *Technological spillovers*

We differentiate technological spillovers between direct and indirect technological spillovers respectively. The direct spillover of technological development is an increase of well-being[8] of one consumer caused by an increase of consumption of the good by other consumers. This spillover effect is represented through a demand effect. The indirect effect of technological spillover is the frame in which technology development provides diverse ex-post services. In the case of renewable technologies ex-post services can be assimilated by an increase of job opportunities (engineer, technician etc) relating to the technological

availability.

- *Network information*

Network information focuses on post-adoption effects of new technologies. The more information about the technology is diffused, the more the adoption of the technology is encouraged. Two advantages can be drawn through an increase of information about technologies. The availability of reliable information reduces risks relating to the adoption process and increases the expected payoff of the adopter. On the other hand, increasing reliable information strengthens the learning experience since an ex-ante information basis is provided in order to facilitate the analysis of experience curve of technologies.

- *Technological interrelation*

This method emphasizes a "snowball effect". Technological development improves the technological supply chain framework and creates opportunities for moving to a new technological dynamic paradigm. For example, an expansion of the chain of renewable technologies (wind, PV etc.) stimulates the development of technological components use as inputs (cilicium, rotor), therefore allowing a strengthening of the existing clean technology

[8] The increasing well-being is represented in terms of an improvement of quality of consumption of the good.

industry. Moreover, the deployment of clean technologies strengthens the electrical industry itself through an affordability of renewable electricity.

Each of these components provides insights into the impacts of decisions to adopt a new technology. Transposing these phenomena through the decision to adopt renewable technologies the IRAs allow fossil-fuel technologies - once selected – to remain preferred by the rest of the actors in the energy market. As the fossil-fuel technologies were more attractive, more developed and more widespread and useful than renewable technologies, then they are more known and familiar.

On the other hand, as exposed above market factors preventing the diffusion of renewable technologies can be also based on the lack of internationalization of environmental externalities generated from classical energy producing technologies. Indeed producing electricity with fossil-fuel technologies generates a degradation of the local and overall environmental quality through a rise of CO2 emissions. In a neoclassical economic prospect, these environmental emissions are supposed to be considered within the tariff mechanism schedule while they produce negative externalities (Jaffe et al, 1999, Baumol et Oates, 1971). However, as the determination of the prices of environmental degradation remains very controversial, only approximate alternatives[9] are proposed in order to integrate the environmental impacts of fossil-fuel energy producing technologies. These alternatives are based on environmental assessment methodologies through which monetary values of environmental pollutants are determined. Renewables are disadvantaged compared to fossil-fuel technologies because electricity prices derived from fossil-

[9] One of the most well known environmental evaluation method in the electricity sector in the context of the European Union is the ExternE model. This model emphasized on impact pathway methodology requires to consider all the step of electricity vector diffusion since the extraction of fossil fuel until the waste disposal

fuel technologies don't integrate the share of this environmental externality. In the literature two mechanisms are advanced in order to take into account these environmental externalities. On the one hand, fixing a proportional tax of the emission level (Pigou,1932; Buchanan, 1969). This mechanism is posited to dissuade private investment but also for not being fully appreciated by final consumers (Jaffe et al, 1999; Foray, 1996). On the other hand, the negative environmental externalities can be internalized following Ronal Coase (1960) point of view by creating a pool market through which pollutant permits could be exchanged between pollutants and polluters. However, even if the debate about proper public policies is still open, one can recognized that none of these instruments have addressed the issue of negative externalities from fossil-fuel technologies. In terms of electricity tariffing, renewable technologies still remain disadvantaged compared to fossil-fuel technologies.

2.2.3 Institutional factors

Beyond technical and market factors, a lack of harmonization of institutional factors[10] can delay the diffusion process of clean technologies in developing nations. To understand the impacts of institutional factors on the diffusion process of renewable technologies one can, for example, refer to the new approach of institutional economics (NIE)[11]. This approach allows us to

[10] The institutional factor determines the reliability of political institutions and safety, public order, violence control, operations of public administrations, operation of the national market, actor coordination, strategic visions, innovations, reliability of contrast transactions, market regulation, social dialogues, social cohesion, social mobility, etc.

[11] Generally speaking, one can distinguish three new institutional approaches (Hall and Taylor, 1996; Thelen, 1999) namely rational choice institutionalism, sociological institutionalism and historical institutionalism. In rational choice institutionalism, economic agents are motivated by the maximization of their self-interest outcome. In fact under this scheme every economic agent behaves strategically for an optimal modification of its fixed preference. In the cases of the

understand relations between different heterogeneous actors and relations between institutions and actors in order to reach a targeted outcome by, for example, investigating how existing routines within societies and policies can either stimulate or block the achievement of this targeted outcome?

Assuming the targeted outcome is to provide a new path towards a clean technology regime, therefore the promotion of renewable technologies should include specifics of the actors in the energy market. These actors could take two forms when it comes to investing in renewable technologies: the potential investors and political structures guaranteeing a reliable investment environment. Since the existing path-dependency structure of fossil-fuel technologies is included in the existing institutional design, the introduction of new clean technologies requires the creation of new institutional designs. The modification of this existing institutional design requires deep investigations in terms of political choice, for example, by facilitating factors encouraging this evolution (i.e. investing in research and development; promotion of civil society, increasing environmental awareness etc.) and by generating a new organizational structure and learning horizon. This orientation is much more important than the nature of institutional cycles encourages (constrain) access of resources and markets. Figure 3 proposes a potential link between institutional components and the modification of technological designs in order to promote deployment of renewable technologies. From figure 3, a combination of different factors - institutional reliability, political orientation, organizational arrangement and regulation artifacts - contributes to the deployment of renewable technologies in the market.

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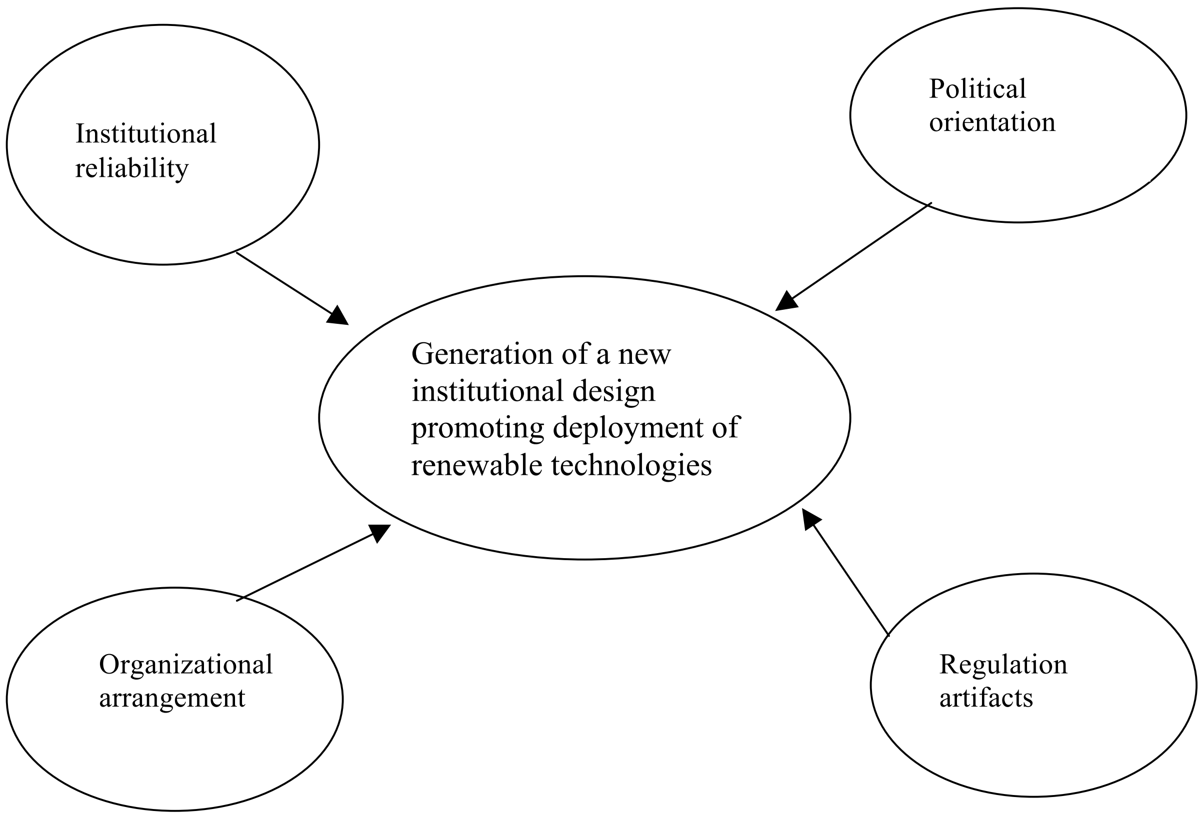
sociological and historical institutionalism cognitive and normative and the explanations of existing reasons of institutions are investigated respectively. For more informations about these three approaches, the reader can refer to the (Hall and Taylor, 1996)

Figure 3: institutional factors promoting deployment of renewable technologies



Although links between institutional design and the promotion of renewable technologies have been rarely investigated, the nature of institutional structures can be considered as a powerful mechanism, able to facilitate (constrain) the emergence of a new technological stage (Rotmans et al, 2001). Considering different actors and competencies, networks and institutions, Jacobson and Johnson (2000) show how the renewable technology development can be stimulated (constrained) by an existing institutional framework (table 2).

Table 2: Factors leading to a new technology being repelled

Actors and markets

- Poorly articulated demand
- Established technology characterized by increasing returns
- Local search Processes
- Market control by incumbents

Networks • Poor connectivity • Wrong guidance with respect to future markets
Institutions • Legislative failures • Failures in the educational system • Skewed capital markets • Underdeveloped organisational and political power of new entrants

Sources : S. Jacobsson, A. Johnson (2000)

Through their investigation, they argue that different components can block the promotion of renewable technologies. These blocking factors can be, among others, a poorly articulated demand, economies of scale and experiences, other sources of increasing returns, local environment and market reliability (Jacobson and Johnson, 2000). The poorly articulated demand is mainly focused on the inability of consumers to expect a high report of price/performance. This poorly articulated demand can, for example, take its origin from high geographical costs constraining a firm to move to places where demand is concentrated. In fact, the spatial areas where firms are located can generate knowledge poles making knowledge delocalization difficult because all knowledge capital is exploited in these geographical areas. In this situation, it could be costly to envisage a delocalization of firms in order to create adequacies between a fall of the report price/performance and the supply.

Furthermore, as (North, 2005) argued, institutions play important roles in the promotion of new technologies in markets. More specifically, in the field of renewable technologies, their implication can be linked to political actions raised in order to provide incentive mechanisms facilitating the transition toward clean technology development. These incentive mechanisms can take mainly two different forms: an “economic instrument” (Jaffe et al., 1999) and/or the “command and control instrument” (Baumol et Oates., 1971). The economic instrument emphasizes the use of economic tools for the diffusion of renewable technology. These tools can include tax policies, subventions and tradable permits. The command and control tools aim to promote - by an institutional modification - the diffusion of renewable energy through portfolio of standards and targets. The choice of one instrument over the other should reflect the objective of each country according to its priorities regarding environmental protection, economic development and socio-economic stability.

All these factors prevent the large diffusion of clean technologies and contribute to maintaining the lock-in framework of renewable compared to classical technologies. Therefore they create a framework of a path-dependency through which a technology adopter chooses the most advantageous technology (Unruh, 2000; Hughes, 1983).

Section 2.3: Lock-in or path dependency of fossil fuel technologies

Arthur (1989) shows conditions and frameworks within which a labeled technology (B) dominates its competitor (D) according to IRAs. Translating this analysis into a relationship between fossil fuel technologies (classical technologies) and renewable ones, one can find the same structure between those two energy generating technologies. The fossil-fuel technologies were firstly chosen - by earlier consumers - compared to renewable technologies. In the framework of IRAs, classical technologies have higher probabilities to remain dominant in the market of energy.

Changing the lock-in (technological path-dependency) of renewable technologies requires a modification of existing technological regimes. In the case of promotion of clean technologies a change of technological regime can be performed through two different options. First, the willingness to increase the renewable energy amount of the total energy portfolio. This can be done by setting up policies and commitments in order to diversify the energy mix in the energy supply portfolio. Second, the modification of the technological regime can be undertaken by considering clean technology development as a radical strategy to change the end-of-pipe process of electricity production. In this framework innovative policies must be supported through a radical change of the electricity supply chain. The table 3 shows the different sources of lock-in of renewable technologies

Table 3: Source of lock-in

Lock-in sources	Examples
Technologic	Dominant design, standard technological architectures and components, compatibility
Organizational	Routines, training, departmentalization, customer-supplier relations
Industrial	Industry standards, technological inter-relatedness, co-specialized assets
societal	System socialization, adaptation of preferences and expectations
Institutional	Government policy intervention, legal frameworks, departments/ministries

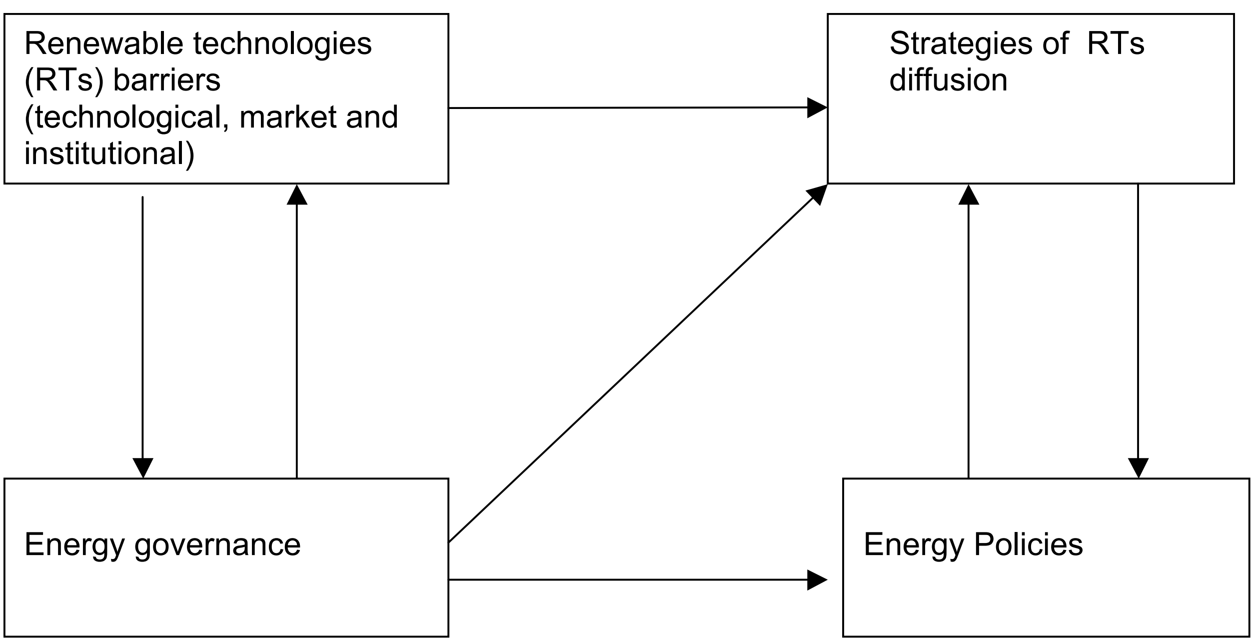
Sources: Unruh (2002)

However, even if the promotion of renewable technologies is constrained by these barriers (technological, market and institutional), we believe that setting good policies could bring renewable technologies in the market and therefore increase their level of diffusion in developing nations. In fact, overcoming these theoretical barriers requires providing insightful strategies of energy governance through which renewable technologies could be brought deeply and strategically into the market. Governing an energy transition could open up opportunities to overcome high-investment costs of clean technologies, stabilize the energy market and harmonize institutional components involved on the diffusion of renewable technologies in developing nations.

Section 2.4: Overcoming existing theoretical barriers via the best governance approaches of renewable energy transition in developing nations.

In the previous sections we have assessed theoretical factors preventing diffusion of renewable technologies in developing nations. It is argued that the success of the diffusion of renewable technologies should be the result of overlapping technological, market and institutional mechanisms. Policies promoting deployment of renewable technologies should put forward an interlinked approach through an investment in factors that decrease technological cost, stabilizing the energy market and provide reliable and stable institutions. Within this framework, we provide strategies of energy governance through which developing nations could stimulate deployment of renewable technology. A proper energy governance strategy is crucial if developing nations aim to increase the share of renewable technologies in their energy portfolio (figure 4).

Figure 4: Links between energy governance and promotion of renewable technologies in developing nations.



Moreover, a proper governance of energy transitions facilitates harmonization of different actors involved in the market of renewable technologies. This harmonization has impacts on both the supply and the demand side. In the supply-side, harmonization of actions reduces transaction costs by facilitating information exchanges and contact interactions between different investors. In the demand-side, harmonization of actions generates convergent demands of consumers. This convergence of energy demand facilitates a set up of energy planning strategies while it reinforces efficiencies of energy policies by reducing, for example, uncertainties. Furthermore, a proper energy governance facilitates the override of barriers blocking the diffusion of renewable technologies. The override of these factors strengthens the abilities of renewable technologies and improves the learning process through an increasing return of experience with respect to the reliability of technology.

In this framework, although it is important to keep in mind the specificities among developing nations, we identify different strategies of energy governance through which deployment of renewable technologies can be facilitated. We differentiate between: state ownership governance, public-private partnership governance (PPPs) and multi-level stakeholder governance.

2.4. a: State ownership supply approach

The state ownership supply approach emphasizes the diffusion of clean technologies through a vertical deployment carried out exclusively by the national government. This can be carried out through government agencies responsible for promoting renewable technologies. This aim is included under government agenda and it considers deployment of renewable energies as a component of public policies. The public planner acts to create markets of renewable technologies and to sustain their growth. In this framework, public authority remains the cornerstone of clean technology deployment. In doing so, the state creates, manages and controls the market of renewable technology. However, it is important to highlight that this approach is hampered by a series of limitations, making the new market of renewable technology unsustainable in the long-term. On the one hand, the presence of public agencies does not guarantee the complementarities of resources. In fact, under this structure, all existing risks and transaction costs are entirely supported by public agencies. Moreover, the state ownership supply approach provides high bureaucratic costs. On the other hand, under this structure, neither disparities of local resources nor specificities of local communities are taken into account. These local resources can be financial (in order to share the amount of capital cost) but non financial as well. The non financial resources can include informal resources like norms, cultures and habits in different localities. These informal resources can have important impacts on the acceptability of renewable technologies in local communities.

2.4. b: Public-private partnership

The second form of energy transition governance proposed can be formulated as a public-private partnership (PPPs). This form facilitates promotion of clean technologies through an introduction of private investors into the supply chain. Under this scheme, a diversification of the supply chain can be carried out by both public agencies and private investors. This diversification reduces the public share of capital cost of clean technologies while it provides financial resource complementarities. Beyond opportunities for the financial mix, PPPs stimulate the creation of a commercial-oriented market for renewable technologies while innovation is better diffused when it is left on private actors (Banales-Lopez et al, 2002). Private actors go beyond niche markets created by public authorities in incorporating their ability to rationalize clean technology deployment. The deployment of renewable technologies through private actors cares more about disparities and specificities among communities than in the case of public actions. Private actors, for example, better integrate on their decision specificities like geographical resource endowment and local constraints since these constraints have important impacts on their financial outcomes.

In the promotion of renewable technologies in developing nations public-private partnerships can take, for example, the following form: Public authorities provide incentive mechanisms and adequate infrastructure, while private actors emphasize on supply chain management in more efficient terms.

Furthermore, beyond resource complementarities and market-oriented schedules of renewable technologies, the advantage to introduce private investors in the supply chain is to stimulate the decentralization of decision-making. This decentralized decision-making process becomes easier to accomplish as PPPs increase the level of knowledge and skills. This learning skill enables private actors to create new possibilities through different skills in order to rationalize their decision-making.

However, although the introduction of private investors has more advantages – in terms of risk management and market-oriented involvement - compared to state ownership approach, it is important to highlight that this approach, once provided alone, contains some limitations as well. For example, it does not incorporated prerogatives of the local population living in areas where clean technologies are going to be implemented. The local population has important responsibilities for the success of the deployment of renewable technologies. The local population represents potential consumers, therefore they have the power to influence public-private decision. Taking into account the local population enables management of cultural and socio-economic realities which can be seen as transactional marketing costs within decision processes.

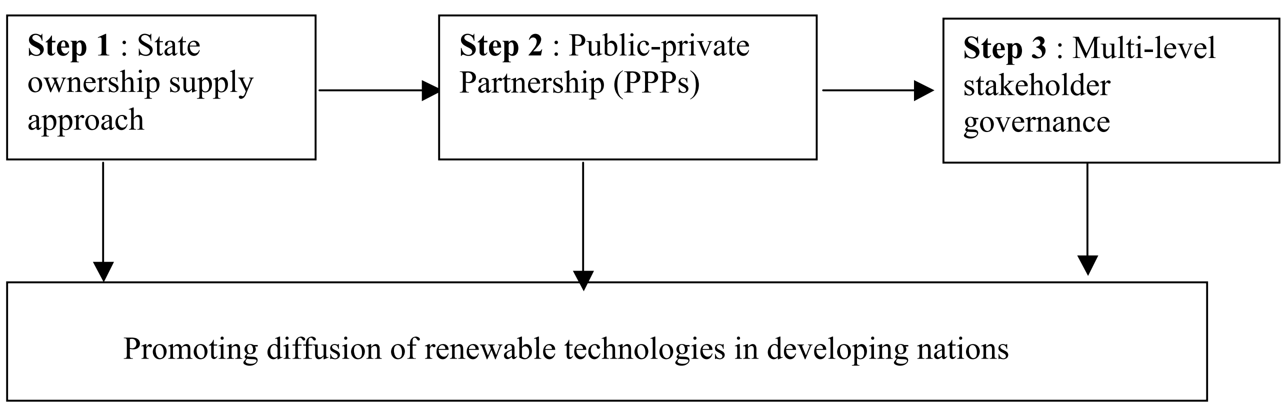
2.4. c: Multi-level stakeholder governance

The multi-level stakeholder governance goes beyond state ownership supply and PPPs approaches by integrating local communities into the decision processes. This combines co-ordination efforts of public authorities, private entrepreneurs and local communities since the energy transition requires multidimensional influences from national to local level. The inclusion of interests of local communities has an important impact on the local acceptance of the energy regime transition. Many studies have argued that local social constraints can block the diffusion of energy technologies (Wüstenhagen et al., 2007; Mallett, 2007; Michalena et al., 2009; Araujo et al., 2008; Sauter et al., 2007; Wamukonya, 2007). Indeed local populations can exert pressure on some initiatives promoting deployment of renewable technologies. These pressures can, for example, take either individual or general dimensions. The individual pressures can be manifested in the change of individual behaviors in order to support targeted objectives. In this context, the pressure can be organized around individual actions in terms of modification of purchase-power decisions or changes of daily personal behavior. On the other hand, pressure can take a collective dimension. In this framework, complaining agents (consumers) combine a change of individual behavior and sensitizing of other agents in order to influence changes in their behavior. This type of pressure is organized through civil society activities, media information, modification of purchase decisions etc.

In the case of clean technology promotion, these pressures can find their legitimacy according to the type of supply schedule provided. For example in the case of renewable technology decentralized options, some actors - farmers, villagers and associations against noises - can be against a development of clean technologies according to their daily activities. The case of wind parks in different countries (UK, France, Netherland) is very illustrative with the "not in my back yard" (NIMBY) attitudes developed by some stakeholders. Beyond facilitating local acceptance of diffusion of renewable technologies, multi-level governance enables the reduction of transaction costs. This reduction can be seen as a fall of marketing and advertising costs. This reduction can be done through cooperative movements and associations which educate and inform the population about advantages of policies in terms of energy security and climate change mitigation.

Therefore the transition towards sustainable energy production could be carried out following these three approaches. During the first phase public authorities create the renewable technology market by providing required infrastructures. As Rai et al, (2009) have argued in the earlier stage (characterized by high uncertainties) success in achieving technology diffusion required a direct involvement of public authorities. Furthermore, in order to rationalize the supply chain, diversify supply risk and to integrate local cultures and norms in the decision process, the introduction of private entrepreneurs and end-user stakeholders could be envisaged in the two and third steps (figure 7).

Figure 7: steps to governing transition towards sustainable energy production path



Section 2.5: Strategies for sustainable energy transition in developing nations

In the previous section we outlined the fact that setting up a new electricity-generating technology regime based on renewable technology requires, on the one hand, identifying barriers constraining their diffusion and, on the other hand, setting up clear strategies based on energy governance. Furthermore we believe that in deeper terms, a transition towards a clean energy generation requires to set up, beyond only energy governance framework, complement specific energy policies strategies. Setting up specific strategies in developing nations stimulates the transition to a clean-technology regime and therefore contributes to promoting sustainable development. The use of renewable technologies can be considered as a strategy of sustainable development for three mains reasons. From the environmental point of view renewable technologies do not emit GHGs during the production phase, which leads to the reduction of emitted pollutants contributing to climate change. From the economic point of view, the use of renewable technology creates jobs during the installation phase as well during the operating and maintenance phases. Moreover, in the long-term, the use of renewable technology reduces the monetary dependence on oil representing in many countries a large expenditure in the national budget. In developing countries, this amount can be devoted to different social issues, such as education and health policies. Finally, from the social point of view, the use of renewable technologies has a significant impact on the social dimensions, particularly in developing countries.

In this framework, the analysis of transitions towards a sustainable development can take two different forms (Verbong and Geels, 2007). On the one hand, this transition can be achieved through a set up of a niche market (Kemp et al, 1998). This process starts by a creation of a sample market in which clean technologies are exclusively reserved. This action is carried out under a radical modification of existing technological designs and institutional structures in order to maintain clean technologies in these niche markets. The maintenance of technologies in these markets, ceteris paribus, modifies the socio-technical landscape. The set up of these markets must be undertaken in an efficient way, facilitating their evolution or at least their “niche branching”. The threat is to avoid generating a niche market which is irreversible and in which technologies developed under this market have no opportunities to move to another niche or to evolve and expand dynamically. In fact, as niche branching improves the adequacy between the technology and market characteristics energy policy-makers must fix conditions in order to enable technologies to survive in the markets. The set up of a niche market reserved for clean technologies improves the reliability of the learning process. This learning advantage can be used as a benchmark in order to improve adequacy between characteristics of technologies and the dynamic evolution of market. The creation of a niche market can be undertaken, for example, through a demonstration phase of projects in order to validate technological concepts. On the other hand, the transition towards sustainable development can be undertaken through a hybridisation process through which a set of alternative technological regimes is proposed in order to diversify the existing technological basis. In fact, a process of hybridisation introduces a technological path into an existing technological regime. The objective is to stimulate the co-evolution of different technological designs. Raven (2007) defines hybridisation as processes in which "new" and "old" technologies hook up to forming some kind of hybrid technical design. Contrary to the strategy of niche building in which new technologies are included in a radical scheme, the hybridisation process uses an evolutionary behavior. The new clean technologies are introduced within a framework of attaining specific goals. For example, under the hybridisation process, one can introduce renewable technologies in order to minimize fuel costs or to satisfy remote location demands. In this context, both of these approaches follow the same goal: to spread diffusion of clean technologies in order to create a sustainable energy transition

Section 2.6: Conclusion

The aim of this chapter has been to provide a conceptual framework through which deployments of renewable technologies in developing nations could be based. . We started by reviewing existing theoretical barriers preventing deployment of renewable technologies in developing nations. We argue that the transition towards sustainable energy production in developing nations should be embedded in an interlink approach coupled with a proper strategy of energy governance. In fact since the energy market involves different technical, economic and social components a harmonization of their actions is required for a more sustainable decision-making. Furthermore a proper energy governance can be formulated through three steps: a state ownership supply approach, a public-private partnership and a multi- level stakeholder governance. As in the earlier stage adoption of new technologies requires sunk-costs investment and is highly risky, the adoption should be started by public authorities. Once the required infrastructures are available and uncertainties are reduced, the involvement of private actors could be encouraged in order to rationalize optimal decision-making.

Chapter 3: Renewable decentralized in developing countries: Appraisal from Microgrids Project in Senegal[12]

Abstract

Sahelian developing countries depend heavily on oil-import for the supply of their increasing energy demand. This setup leads to an imbalance in the balance of payment, an increase of debt and budget asphyxia, whereas renewable resources are widely and abundantly available. The objective of this paper is to carry out a feasibility analysis of off-grid stand-alone renewable technology generation system for some remote rural areas in one Sahelian country. A survey conducted in 2006, within the framework of microgrids project, in rural areas located in three different regions in Senegal (Thies, Kaolack and Fatick) permits determination of demand estimations. Two reference technologies are chosen, namely a solar photovoltaic (PV) system of 130 Wc for solar endowment and a wind turbine of 150 W for wind speed. Taking into account the life-cycle-cost and the environmental externalities costs, our results show that the levelized electricity costs of PV technology are lower than the cost of energy from the grid extension for all these three regions. Thus, decentralized PV technologies are cost-competitive in comparison to a grid extension for these remote rural areas. For wind technology viabilities results are attained with a requirement demand lower than 7. 47 KWh/year for Thies and 7.884 KWh/year for the two remaining areas, namely Kaolack and Fatick. The additional advantage of the proposed methodology is that it allows the environmental valuation of energy generated from non-renewable resource.

JEL classification:: Q42 Q49 Q51

Keywords: Electricity access ; Renewable technology ; Environmental externalities ; off-grid

[12] This chapter is a slightly adapted version of Djiby-Racine Thiam, 2010. "Renewable decentralized in developing countries: Appraisal from microgrids project in Senegal" Renewable Energy, 35, pp 1615 - 1623

3.1. Introduction

In rural zones of developing countries, access to energy is a paramount importance, as it increases the standard of living of rural populations by facilitating, on the one hand, the struggle against poverty (Karekezi et al, 2003; Karekezi et al, 1997; Kaufman 2000; Martinot et al, 2002). On the other hand, it improves the quality of life with the creation of comforts for populations via the acquisition of goods such as radios, televisions and mobile phones (Jacobson 2006; world bank, 2003). Considering particularly Sahelian countries, energy access remains until now relatively low, while the renewable resources – wind speed endowment and sunny radiation potential – stay widely abundant. The endowment of renewable resources assumed that resorts to renewable technologies could increase and improve energy access particularly in remote rural areas (Maiga et al, 2008). According to that preceding assumption a new and straightforward technique to analyze the cost-effectiveness of renewable technology's adoption in rural areas is required.

The purpose of this paper is to verify this assumption. In fact we compared two different electrical planning expansion policies. The first one focused on the centralized-national network expansion while the second decentralized stand-alone renewable technology scheme. The first option, national network extension, used the conventional diesel technology while the second dealing with stand-alone renewable decentralization mobilized a wind turbine and photovoltaic panel. The life-cycle-cost analysis is retained in this paper. This methodology is performed to quantify and compare the monetary value of energy produced from electricity generation technology. It refers to the total cost of ownership of all selected technology over the lifetime of their operation. Numerous lifecycle-cost analyses have been carried out over renewable technology stand-alone generation (Nguyen, 2007; Bhuiyan et al, 2000; Bugaje, 1999; Kolhe et al, 2002).

This study will be applied to the case of Senegal principally for two reasons. First, we judge that this country remains a suitable representative of the Sahelian countries. Furthermore, a survey carried out in the framework of the microgrids project[13] allows us to work with data of potential

[13] The Microgrids project was promoted and financed by European Commission. Its goal is to promote the development of micro-networks and renewable resources for facilitating electricity access in rural areas in Senegal. This project was included in the context of poverty reduction scheme within the context of Millennium Development Goal (MDG) targets. This latter promoted by United Nations (UN) and developed countries targeted to reduce poverty depth in 2015, around the world developing countries

demand assessed into the selected zones. Three regions have been selected for this project namely (Dakar, Thies and Kaolack). A survey was carried out in thirty villages for the determination of electrical power and energy they need.

Situated on the west coast of the horn of Africa, Senegal is located between 12 and 17 degrees northwest and extends over an area of 196 700 km2. The population was 12 million in 2007 (ANSD, 2007). It is growing at an annual rate of 2.5%, remaining higher than that of the countries of the OECD[14] which is an average of 1.6%. Close to half of the population (49%) lives in rural areas (ANSD, 2007). Economic activity remains dominated mainly by the service sector, which contributes to 62.5% of GDP versus 19.2% for the industrial sector and 18.3% for the agricultural sector (ANSD, 2007). Despite the low level of contribution of the agricultural sector in the economic growth, it mobilizes more than 50% of the population activity and is particularly focused in rural regions.

Energy consumption per capita (0.19 toe[15]) remains one of the lowest in the sub-region compared to the average of the Economic Community of West African States (ECOWAS) which represents (0.45 toe) and that of the sub-Saharan African region (0.50 toe) (SIE, 2007). In order to increase the level of electricity access in both rural as well as urban areas a reform of the electric sector had been undertaken. In fact, the traditional electricity supply system via the extension of national network has not delivered satisfactory results. Levels of access, in 2006, remains dichotomized with urban electrification rate (60%) representing four times that relating to rural zones (15%). The lack of infrastructures in rural zones makes electricity access from grid-expansion very costly. Despite the low level of access to electricity, the country has at its disposal a considerable potential in terms of renewable energy resources. Moreover, renewable energy could prove profitable when exploited effectively, particularly for the supply of energy to rural areas located far from the electricity distribution network. The country receives at least 3000 h of sunshine per year (Alzola et al, 2009) and the average solar energy received is estimated in 2.000 KWh/m2/an (Youm et al, 2000). In regard to wind energy, the northern zone possesses fairly significant potential which could be turned to profit generation if exploited (SIE, 2007).

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[14] Organisation for Economic Co-operation and Development.

[15] Ton oil equivalent

In this context, questioning the effectiveness of stand-alone decentralized-renewable technology against current national network expansion should be interesting to help energy policymakers, but also microgrids managers, to provide an optimal solution about the capacity planning expansion in remote rural areas.

Furthermore, decentralized electric supply, via the use of renewable technologies, presents some advantages compared to the extension of the electrical grid (Karekezi et al, 2002; World Bank, 2003; Maiga et al, 2008; Chakrabarti et al, 2002; Cropper et al, 1994; El – kordi et al, 2002; ESMAP, 2007; Evander et al, 2004). Renewable technologies do not require fossil fuels for their operation, thus price variations of fuel do not affect the quantity of electricity produced nor the performance of the energy system. From an environmental point of view, they do not emit greenhouse gas emission (GHG) during the electricity-production phase (Turkenburg, 2000; Owen, 2006). Moreover, being situated close to the point of demand renewable technologies use can save costs relating to electricity transport and distribution. From an economic point of view they improve local employment situation during the installation phase but also during the operation and maintenance process.

In order to investigate these issues this paper is composed in five sections. The description of Senegal's energy sector will be exposed in the second section (Section 2). The third section (Section 3) will expose and explain the methodology retained. The fourth section (Section 4) presents the results and the last section (Section 5) will conclude the paper.

3.2. Description of the energy structure in Senegal

Like many non-oil producing countries in sub-Saharan Africa, the electricity sector in Senegal is characterized by a dependence on petroleum imports (see Fig. 1). The share of energy produced from fossil fuels is highest as compared to all existing energy sources. Moreover, the increasing effects of fossil fuel imports (78%) over the last six years have produced an imbalance in the balance of payment, since 42% of goods exportation benefits are allocated to the payment of fossil fuel imports (SIE, 2007). The solar energy, hydroelectricity and energy produced from natural gas remains smallest among all these available resources (Fig. 1).

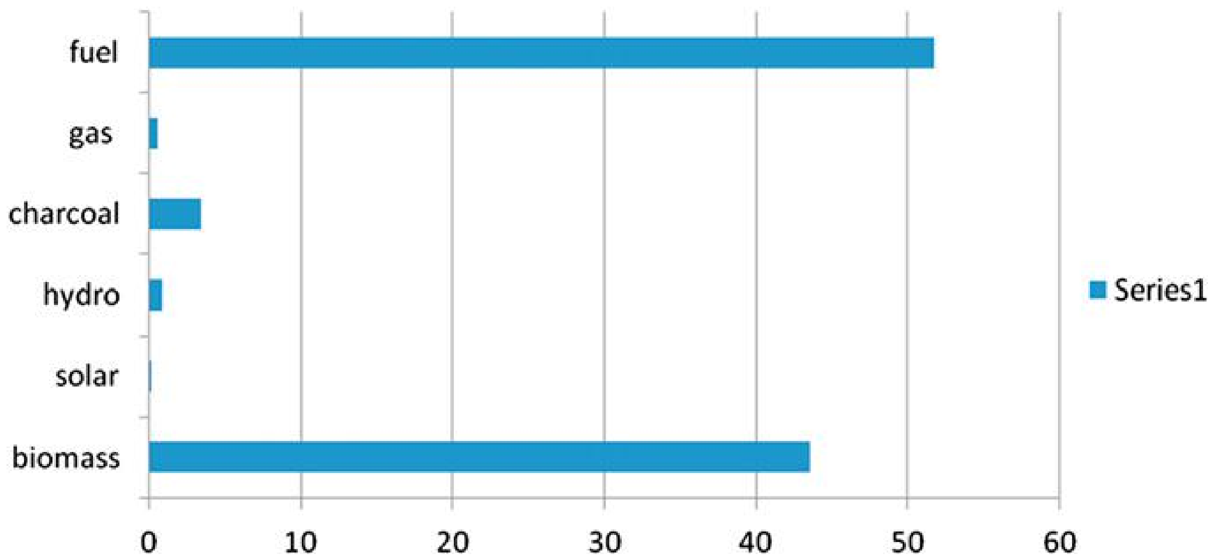

Fig. 1. Structure of energy resources consumption in Senegal (2006) (Kgoe) Kilogramme oil equivalent (kgoe)

Furthermore, more than 40% of energy supplied comes from biomass sources. This latter is composed of wood energy and charcoal. The wood energy is the principal source of energy consumption in rural areas while the charcoal is widely consumed in urban and semi-urban areas (SIE, 2007). The availability of biomass resources as a source of energy supply generates a number of ecological and economic concerns. In the economical point of view, the overexploitation of biomass resource leads to the under valorization of renewable resource price. Moreover, it leads to the free evaluation of the biomass resources whereas its scarcity will be managed by the next generation. About the environmental concerns it is argued that the overexploitation of biomass conducted to deforestation and loss of biodiversity (Cropper et al, 1994; Hyde, 1993; Thiele, 1995).

Electricity production is derived mainly from thermo plants which provided close to 83% of production as well, since 2002, as by the hydroelectric dam of Manantali. This latter possesses a capacity of 200 MW within which 35% is intended to be consuming by Senegal. Despite the increase of capacities by the introduction of additional thermo plants, consumption still remains quite low when compared with other sub-Saharan African countries. Table 1 shows the level of Senegal's energy consumption compared to a number of Sub-Saharan African countries. However the major part of electricity produced is consumed by urban populations (SIE, 2007). While rates of access to electricity in urban areas approaches 76% those of rural areas remains around, in 2006, 16%.

Table 1: Energy consumption per capita of urban and rural populations (Kgoe).

Countries	Urban	Rural
Kenya	220	60
Zimbabwe	300	150
Botswana	390	166
Zambia	200	180
Senegal	170	120

Sources: African Development Bank, 1996.

This low level of access to electricity in rural districts compared to that in urban areas has motivated reforms implementation in spite of consistent budget constraints. In fact in 1998, under the initiative and assistance of the World Bank, the government implemented reforms in the energy sector via the publication of the white paper dealing to the development policy of energy agenda. This latter was composed of three main targets. The first one aimed at the dismantlement of the own-state monopoly electric company (SENELEC[16]). This intended to hang up the involvement of the national and international private sector in order to facilitate and promote the public–private partnership. The second aimed to increase energy supply for a major part of the population particularly in remote rural areas. It leads to the creation of an agency focusing exclusively on rural electrification access topic (ASER)[17]. Its function can be summarized in two points. It has, as its principal mission, to develop and provide programs relating to rural electrification. Furthermore, to choose operators and attributes concession rights for any rural electrification program. The final reform orientation aimed to promote the dissemination of renewable energy technologies, particularly in the rural regions. Because the presence of abundant renewable resources seems to provide a good opportunity to promote, encourage and disseminate the diffusion of renewable technologies. However, almost a decade later, the results of the reform remain mitigated in the fact that the electricity sector is still not able to supply electricity to a substantial portion of the population (ref. Table 2)

[16] Société Nationale d'électricité du Sénégal.
[17] Agence Sénégalaise d'électrification rurale

Table 2: Electrification rates in both urban and rural areas (percentage).

Years	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Rural	1.5	1.9	2.4	3.1	4.1	4.1	4.4	4.7	5.0	6.4	7.6	7.5
Urban	45.8	46.5	47.3	48.2	49.2	51.3	49.5	50.3	51.4	51.3	52.6	55.4
Total	21.2	22.0	22.9	23.8	25.1	26.3	25.8	26.6	26.9	28.3	29.8	31.4

Sources: SENELEC (Société national d'électricité du Sénégal).

3.3. Methodology

The methodology developed is an extension of that used in Nguyen (2007). We introduced, in distinction to the above-mentioned author, the analysis of external effects, so as to take into account the external costs stemming from the use of fossil fuels for the production of electricity. Furthermore, our approach is inspired on life-cycle-cost6 analysis rather than simple comparison between capital costs. It is composed of four steps. Firstly an analysis of selected technologies is performed. This permits determination of economic and technical factors. Then we determined the quantity of electricity produced by renewable technologies under the meteorological conditions of the three selected areas. An assessment of environmental costs, which is supported by emissions factors, will be presented in a third step. In the final stage, environmental costs integrated into an economic assessment allow the determination of the levelized-electricity-cost. This latter criterion allows us to compare the choice of stand-alone decentralization option via renewable technologies with that of centralization scenario using current national network extension. This criterion remains the most used in terms of comparison of electricity production technologies. Even if some suspicious remain about their reliability when uncertainty is included into the technology generation investment (Roquest et al, 2006). It represents the unit cost in KWh of electricity produced by a given type of technology. Its particularity over against criteria can be situated on two levels. Firstly, it compiles and integrates, beyond a simple comparison of capital costs, all operating, replacement, maintenance, transport and connection costs of the technologies considered. Furthermore, it takes into account also fossil fuel and environmental costs of conventional technologies. Total costs are considered in discounted value taking into account the discount rate, interest rate, and the variation of fuel cost. The following Fig. 2 shows the framework of the life-cycle-cost as an approach carried out in this paper.

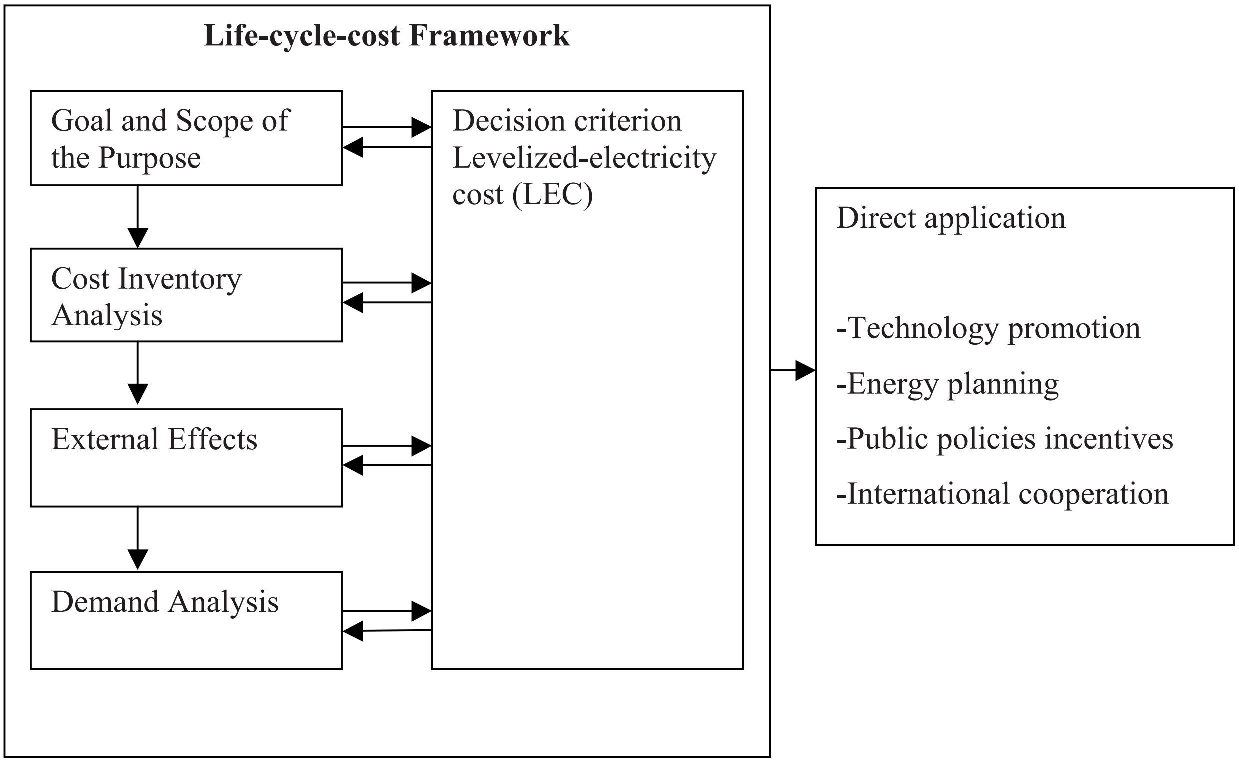

Fig. 2. Life-cycle-cost framework.

3.3. a: Analysis of selected technologies

The photovoltaic (PV) modules produce electricity by directly converting the sun's rays into electricity. The electricity produced is delivered in the form of D.C. current, which is perfect for numerous applications. However, that involves a transformation to alternative course if it is required to be introduced into a distribution network. The energy captured by a module depends on the surface, the nominal power of the panel and the duration of sun exposure. This latter varies according to latitude, season, time of day. However, taking into account the intermittent features of renewable technologies (Owen, 2006; Weisser, 2003), the majority of photovoltaic (PV) modules not connected to the distribution network use batteries. The PV-battery power system permits storage of the energy supply during periods of variable meteorological conditions, allowing equilibrium between energy supply and demand. In rural areas of developing countries, this type of technology is highly appropriate for responding to the energy needs of the population (Karekezi, 2002). In the case of wind turbines, kinetic energy is converted into mechanical energy or electricity via the rotation of the turbine. The power captured by wind turbine is a function of the square of its diameter and the cube of wind speed. When favourable meteorological conditions are met, wind technologies represent a good alternative method for supplying electricity. In the rural areas of the three regions studied (Kaolack, Thies and Fatick) small wind turbines are quite appropriate for the various end-use electrical appliances.

Although more costly as compared to those of conventional technologies, the costs connected to renewable technologies have come down significantly during the last few years (Fig. 3) with Ci representing the costs of electricity. Advancesin research and development and the emergence of the assembly market in developing countries have lowered the cost of renewable energy technology unit. Furthermore, it is argued that (ESMAP, 2007; Bordier, 2008), the learning process of renewable technologies remains susceptible to decrease in the next future years as since more than the last twenty years.

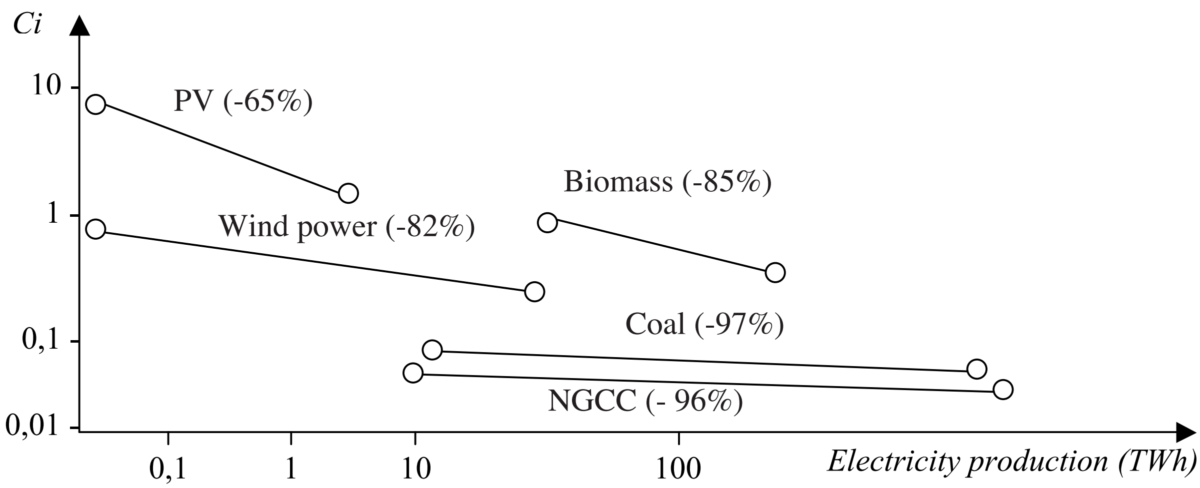

Fig. 3. The learning rate of different renewable technologies (percent)
Source: Bordier (2008)

Three kinds of technologies are mobilized. The decentralization option is composed of a solar photovoltaic module with a capacity of 130 Wc and a wind system with a capacity of 150 W while the centralized option based on the extension of the distribution network used a diesel group with a capacity of 450 W. This type of conventional technology has been selected because it corresponds to that being used currently in Senegal for the production of electricity. About renewable technologies, they are in general use, during projects phases in rural parts of Senegal. Their utilization started to be discovered and they are compatible with local conditions and resources endowment. Technologies selected are evaluated through their costs. The latter include capital costs, costs incurred during operating and maintenance, to which must be added environmental, transport, distribution and connection costs when referring to centralized option. Capital costs are composed of the cost of equipment, including engineering costs, and all costs related to installation. On the other hand, operating costs vary according to the option considered. In the framework of a choice in favour of decentralization, incorporating renewable technologies, operating costs are composed of the cost of operating and maintenance. While in the case of centralization, including the diesel group, operating costs are composed of costs of maintenance, costs allocated to the consumption of fossil fuels. These two following (Tables 3a and 3b) present the technical and economical characteristics of the selected technologies during the production and the transport of electricity.

Table 3a: Technical and economic features of selected technologies (production).

	PV. Tech	Wind Tech	Diesel Tech
Capacity	130 Wc	150 W	450 W
Capital cost (F CFA)	350 000	160 000	185 000
Op and maintenance (FCFA)	1500	2000	9500
Life expectancy (years)	20	10	3
Capacity. battery (Am)	100	100	
Battery cost (FCFA)	35.000	35.000	
Lifetime battery (years)	3	3	
Charge controller (FCFA)	25.000	25.000	
Lifetime controller (years)	10	10	
Fuel tank investment cost (FCFA)			15.000
Lifetime tank (years)			3
Unit cost of delivered fuel (FCFA/m3)			210/m3
Heat rate (Kj/KWh)			11.000

a International Energy Agency (IEA) ; Service de l' énergie en milieu Sahélien (SEMIS) ; ENDA-TM Sources: Compilation by the author based on various sources, including (IEA, SEMIS, ENDA-TM, SENELEC). Values are expressed in Francs CFA ($1 US = 489.207. F. CFA).

Table 3b: Technical and economical features of selected devices (Transport).

Line medium tension	
Long-term marginal cost of electricity provided (cost of 1 KWh transported via the network) (FCFA)	36.000
Exploitation cost (CFA/km/)	240.000
Length (km)	10
Operating and maintenance costs (FCFA/km/year)	82.500
Lifetime (years)	40
Transformer	
Cost of transformer (CFA/transformer)	2.000.000
Operating and maintenance costs for transformer (CFA/transformer/year)	60.000
Life expectancy (year)	40
Line low tension	
Exploitation cost (CFA/km)	145.000
Operating and maintenance costs (CFA/km/year)	161.000
Connecting costs (CFA/clients)	22. 500
Life expectancy (year)	40
Loss (as a percentage)	15%

Source: ENDA-TM

However, deployment of an analysis of the life-cycle-cost requires to taking into account environmental costs linked to the consumption of fossil fuel. Furthermore, external costs vary when one compares conventional and renewable technologies. For example wind and photovoltaic systems can involve higher installation costs than diesel groups or gas turbines but they required relatively low operating and maintenance costs and do not involved use of fossil fuels for their functioning. Following Nguyen (2007) and integrating environmental costs let us consider the expression of life-cycle cost as the following expression.

$$LCC = C_c + C_m + C_R + C_f + C_e \qquad (1)$$

Where *LCC* represents the life-cycle-cost

- Capital cost (*Cc*)

Capital costs are those linked to the purchase of all system components, such as generators, PV units, batteries and extension costs for tension lines. They are generally defined as the initial acquisition costs for equipment before installation begins. These costs are exogenous for each option, centralized or decentralized, considered.

- Operating and maintenance cost (*Cm*)

Within a long-term perspective, technologies employed must include maintenance costs. These costs vary according to the options considered. This expense is low for renewable technologies as compared to conventional technologies.

$$C_m = AnnCm\left\{\left(\frac{1+i}{r-i}\right)\times\left[1-\left(\frac{1+i}{1+r}\right)^N\right]\right\} \qquad (2)$$

where i represents the annual inflation rate, r the discount rate and *AnnCm* correspond to annual real operating and maintenance cost and finally *N* represents the lifetime of the technology in years.

- Replacement cost (C_R)

This represents the costs involved during the replacement of certain system components that have a lifetime shorter than that of the project. They can also include replacement costs related to wear and tear of certain devices. Where N_j represents the life time of the last component of the system replaced before the N years and V the number of component with a life time lower than N years.

$$C_R = \sum_{j=1}^{V}\left\{item\cos t * \left(\frac{1+i}{1+r}\right)^{N_j}\right\} \qquad (3)$$

- Fuel cost (*Cf*)

These costs measure expenses carried out, during consumption of fossil fuels, for the operation of conventional technologies. These costs are zero for renewable technologies as deployed for a decentralized option

$$C_f = AnnC_f\left\{\left(\frac{1+p_f}{r-p_f}\right)\times\left[1-\left(\frac{1+p_f}{1+r}\right)^N\right]\right\} \qquad (4)$$

where Pf represents the annual rate of increase of fossil fuel price

- According to World Bank (2005) we assume that the discount rate represents 4.5%.
- We assume an annual inflation rate of 3%, as recommended by the Central Bank of West African States.
- The inflation rate for fossil fuels, evaluated on the international database, assumes an annual average trajectory of 3% over the last sixty years.

- Environmental cost (*Ce*)

This cost measures external effects generated by the use of fossil fuels. This cost computes the environmental externalities of the utilization of fossil fuel for electricity generation. This cost is also zero for renewable technologies as we consider these latter technologies do not emit pollutants during their electricity-production periods. The environmental cost can be represented by the equation below.

$$C_e = HR \times EF \qquad (5)$$

where *HR* represents the heat rate and *EF* represents emission factor. The heat rate is measured in (Kj/KWh). The emission factor is measured in (kg/Gj) and it measures the efficiency of thermal generating station.

3.3. b: Renewable energy supply

Determination of levels of energy production from the utilization of renewable technologies is undertaken under meteorological condition of these three selected areas (Kaolack, Thies and Fatick). In the case of wind technologies, the energy produced varies according to the cube of the wind speed. However in order to determine the quantity of energy produced a good knowledge of wind speed distribution is required. The Weibull function permits determination of the distribution of the speed. Following Nguyen (2007) the distribution function can be represented as follow.

$$f(v_r) = \frac{\pi v_r}{2(v_{mr})^2} \exp\left(\frac{-\pi}{4}\right)\left(\frac{v_r}{v_{mr}}\right)^2 \quad (6)$$

where v_{mr} represents the average wind speed for the regions considered, v_r the annual wind speed for regions. From the above equation, annual energy production can be calculated according to IE (2000), using equation (7).

$$q_w = \sum_{t=1}^{T} \gamma_w \times f(v_r) \times p(v) \times 8760 \quad (7)$$

with $P(v)$ representing the power of the turbine, $f(v_r)$ the probability density of the Rayleigh function[18], γ_w the efficiency factor of the system and 8760 the number of hours per year. In the context of photovoltaic technologies, production depends on the surface utilized, nominal power of the module and the daily rate of radiation. According to IE (2000) the production of photovoltaic electricity can be estimated using the following equation.

$$q_p = \gamma_p \times X_p \times \frac{b_r}{b_{0r}} \times 365 \quad (8)$$

where X_p is the maximum capacity of the photovoltaic unit, b_r represents the annual average rate of solar radiation in a given region (W/m2/jour) , γ_p the efficiency factor of the system and b_{0r} the rate of radiation standard for each region and 365 is the number of days per year.

3.3. c: Environmental externalities

It is argued that the assessment of environmental effects of energy production plays an important role in the competitiveness of renewable energy technologies (Van der Zwaan and Rabl, 2004; Rabl and Van der Zwaan, 2003). Baumol and Oates (1988) and Pearce and Turner (1990) argue

[18] The Rayleigh function is the value of the weibull function when the charge factor is equal to two (Nguyen, 2007)

that the externality is hold if the economic activity of an agent has an effect on the well-being of another agent, in the absence of any commercial transaction. In the framework of energy production these external effects can be assimilated into the emissions generated during the different phases of electricity production, transport and distribution. In particular, these depend on the characteristics of the technology under consideration[19] as well as the quantity of fossil fuel used.

Taking into account environmental externalities remains quite profitable for the diffusion of renewable technologies. Albeit, this latter does not contribute to the greenhouse gas emission (GHG) increasing, it provides environment benefits to remote rural areas in Senegal. Furthermore it is often argued that the utilization of renewable technology generates a good environmental effect in rural areas of developing countries (Spalding-Fecher et al, 2003; Spalding-Fecher, 2005). I gathered main effects within which renewable technology utilization could contribute to the environment well-being saving and a standard of living improvement in rural areas in Senegal Table 4.

Table 4: Impacts of photovoltaïc and wind technology adoption in rural areas in Senegal.

► Environment	• Lowering of pollution emissions • Decreasing a biomass consumption • Improvement in vegetation cover
► Health	• Reduction of respiratory problems • Reduction of infant mortality
► Equity	• Time gain for female population, following a reduction in time collecting wood for energy use Education
► Education	• Increasing of day length via night lighting • Time gain for children
► Social	• Creation of social ties (nighttime discussions, etc)

Sources: Inventoried by author

[19] It is important to note that effects, such as the age of technology, types of fossil fuels used, efficiency of technologies and the installation of emission controlling equipment can have a strong impact on the pollution level from other pollutants except on carbon dioxide.

3.3. d: The determination of environmental cost

The evaluation of external costs is performed taking into consideration emission factor (*EF*). Table 5 shows the different values of various emission factors of Senegal's energy sector.

Table 5: Data on emissions factors.

	Oil	Diesel	Natural Gas
CO_2 (kg/GJ)	36.7	37.05	28.05
NO_x (mg/GJ)	0.15	0.0824	0.34
SO_x (mg/GJ)	0.998		0.34

* Data on CO_2 emissions were collected at the IPCC Guideline 2006 for National Greenhouse Gas Inventories. These data correspond to emissions factors focused on level I.
* Emissions factors for other pollutants (NO_x and SO_x) come from the report of the Senegalese Association of Standardization (SAS). These correspond to emissions standards that the energy producer must respect under normal operating conditions.
Sources: IPCC + SAS.

The evaluation of external costs is undertaken on the basis of the following values: 5.666 $/kg of SO_x; 2.293$/kg of NO_x and finally 0.018 $/kg of CO2. The latter, provided by El-Kordy et al (2002) represent estimations of the effects on both health and the degradation of the environment due to polluting emissions. These costs, when discounted, will be introduced into the life-cycle analysis so as to determine the levelized-electricity-cost of these different technologies. The assessment of environmental costs remains a difficult issue to accomplish in the context of developing countries, particularly in sub-Saharan Africa. Moreover, the well-know model inquiring environmental effects of energy production carried out in Europe (ExternE) requires very intensive data collection. This model emphasized on impact pathway methodology required to consider all the step of electricity vector diffusion since the extraction of fossil fuel until the waste disposal. Fig. 4 depicts the process steps of the oil-to-electricity fuel cycle. At the moment it will be difficult to assimilate this model in the context of developing countries. The lack of quantitative data, the low level of environmental sensitivity, and the presence of a significant informal economy, made difficult this kind of analysis. The present paper intends to lay out the environmental damages of electricity production in Senegal using emission factor.

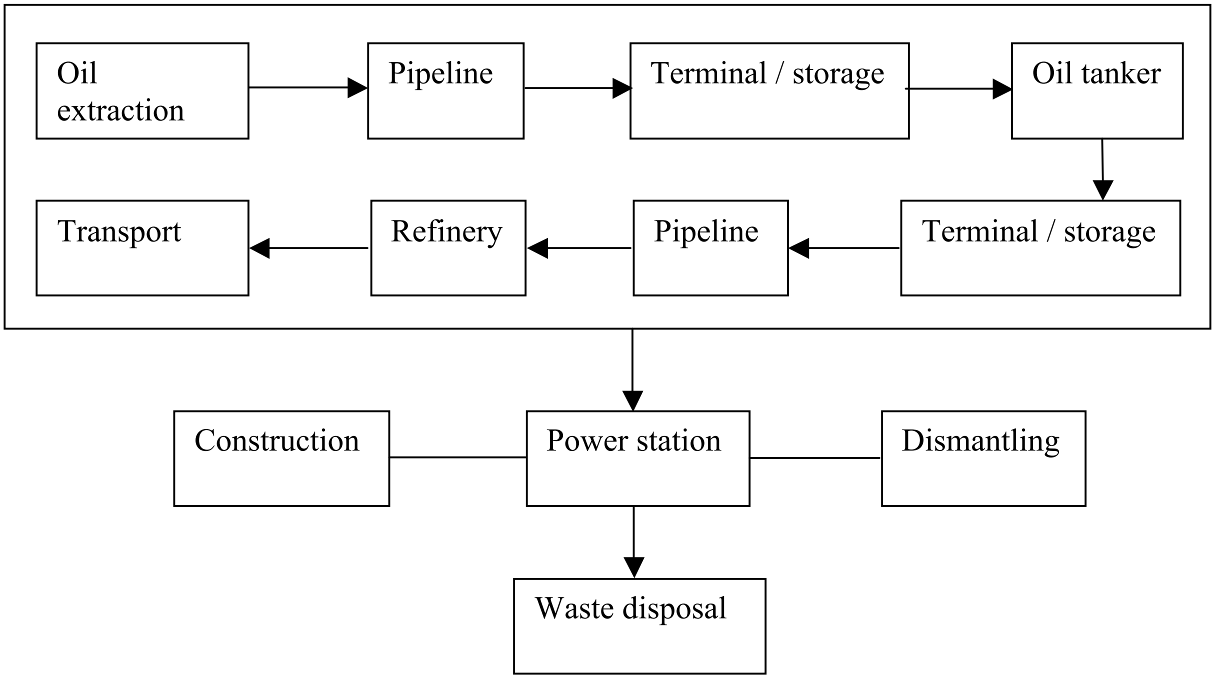

Fig. 4. Pathway analysis of Environmental effect in Energy Industry
Sources: ExternE (1995).

3.3. e: The assessment of energy demand

Like exposed earlier, the analysis of energy demand is based on a survey carried out within the context of microgrids program. Instead a survey had been undertaken between September 18 and October 5, 2006 in three different regions of Senegal (Fatick, Kaolack and Thies). Three kinds of surveys have been conducted. Namely the village surveys, the household surveys and finally the technical surveys (Alzola et al, 2009). The village surveys were carried out by interviewing people chosen by the chief of the village. The household surveys were mainly processed in two steps. A contingent evaluation was carried out, in the first step, with the aim to determine the willingness-to pay for electricity access. Some ‘‘strategic bias’’ was probably present so that the true willingness-to pay was probably higher than that defined during the survey. Moreover, the second step emphasized to collecting data concerning domestic behaviours related to energy consumption. Finally the technical surveys allow listing the driving forces and productions units (Alzola et al, 2009). Thirty non electrified villages were selected; thirteen in the region of Kaolack, seven in Fatick and finally ten villages in Thies. Thirty-four households survey sampling were performed in these villages. Two criteria guided the choice of the selected villages. One criterion was the distance issue, all the villages are situated within a radius of 10 km from the SENELEC distribution network. To simplify we assumed that the distance to grid-connection is lengthened to 10 km. A second selection criterion was that related to the population of each village under study. The villages have been divided according to number of inhabitants, into three types of villages: the small villages, medium-scale villages and large villages. The small villages are these with a population varying between 250 and 350 inhabitants, medium-scale villages are these varying between 500 and 750 inhabitants, and finally large villages are composed of 1000–1500 inhabitants. However, according to the nature and capacity of technologies considered in this article, only the demands of small villages will be experimented in this paper. The technical capacities of the selected renewable technologies coupled with the meteorological conditions in the three different regions do not allow the satisfaction of medium-scale and large village requirements. Moreover, the microgrids project aimed to build micro-network, allowing the supply of electricity to remote rural areas, with capacities higher than those selected in this paper. Obviously with higher technical capacities we could satisfy energy demand from all type of villages with various sizes. But in a decentralized–stand-alone option, technologies selected can be quite different to those selected in a micro-network option (Camblong et al, 2009). Like this paper is dealing with stand-alone option, technologies came up should be socially acceptable and technically feasible. Furthermore, these selected technologies are not unrealistic, because they have been implemented during the PROVEN[20] project, which aimed to reduce poverty level in rural areas of Casamance. Their use has been mastered and they are compatible with local conditions and resources. They have acquired a level of social acceptability, which confers them a fairly wide advantage in terms of dissemination. Analysis of demand levels is based on the two principal steps. Substitute energy expenses are determined, in the first instance, so as to permit calculation of the level of electricity service that ought to be appropriate for one household. Moreover, like expressed earlier, a contingent assessment was conducted allowing the determination of monthly willingness – to pay by households for electricity services. The combining of these two steps permits a characterization of energy needs of households. Table 6 presents the various estimates of demand for these three regions. We note that maximum consumption held in the region of Fatick despite the fact that only seven villages

[20] PROVEN was a project funded by the « Fondation Energie pour le Monde ». Like lot of small-scale projects in Africa, they targeted to promote best practice approaches of off-grid rural electrification using renewable energies in rural Africa.

were investigated. The region of Kaolack, where one finds the largest number of villages investigated, presents the lowest levels of consumption.

Table 6: Estimation of electrical energy demand

Regions	Kaolack	Fatick	Thies	Total
KW/day	7.77	13.05	12.82	33.64

Sources: Microgrids Project Final Report

3.4: Results

As argued earlier the levelized-electricity-cost (LEC) was chosen as a decision criterion for the choice of a competitive technology among the three technologies pertained. In order to evaluate the levelized-electricity-cost we first determined the quantity of electricity provided. This variable is come up in discounted value.

$$QE_f = \frac{(kwh.produced)j}{(1+r)^N} \qquad (9)$$

QE_f represents the quantity of electricity provided by each type of technology; j the number of technologies employed $(j = 1,2,3)$; r the discount rate and N the number of years under study. According to Weisser (2003) the levelized-electricity-cost can be obtained while dividing the total cost from equation (1) by the quantity of electricity provided from the preceding equation (9).

$$LEC = \frac{LCC}{QE_f} = \frac{LCC}{\frac{(kwh.produced)j}{(1+r)^N}} \qquad (10)$$

In this article, thirty rural areas situated in three different regions of Senegal (Thies, Kaolack and Fatick) were analyzed. Three types of technologies were considered. A diesel generator with a capacity of 450 W for centralized scenario, a decentralized-renewable option which included both a wind turbine with a capacity of 150 W and a photovoltaic panel with a capacity of 130 Wc. Our methodology inspired of life-cycle analysis provided the levelized-electricity-cost for the different technological options.

However, according to meteological conditions in these selected areas, the levelized-electricity-cost (LEC) of renewable technologies (PV and wind) are identical for two regions included in the paper (Kaolack and Fatick)[21]. Instead these regions present the same meteorological conditions. This uniformity at the level of meteorological issue justifies also the energy produced for renewable technologies, using the Weibull function, for the two above mentioned regions. As a result, in terms of the cost associated with the life-cycle-process, these areas present the same value. About wind technologies, the competitive LEC corresponds to the unit cost of one KWh produced, not exceeding 7.47 KWh/year for Thiesand7.884KWh/year for the regions of Kaolack and Fatick. In fact, taking into consideration meteorological conditions, wind production is 7.47KWh/year for Thies and 7.884KWh/year for the regions of Kaolack and Fatick. However, as demand (cf. Table 6) is higher than potential wind energy supply, the wind technology doesn't presents viability results in our example, as the LEC is tied to a production level lower than the demand requirement for all three areas.

Table 7: Levelized-electricity-cost of technologies employed in all three Regions. (F CFA).

	Kaolack	Thies	Fatick
Diesel Group	757.88	570.45	410.98
PV Techno.	102.865	73.4638	102.865
Wind technology	115.813	122.23	115.813

We assume a rate of loss of 15% at the level of electricity distribution.
We also assume that the transport network is made up by an average line of 9 km and a low line of 1 km.

Finally it can be noted, from Table 7, that the diesel technology presents the higher levelized-electricity-cost. As a result, it is not competitive as compared to PV technology. Beyond the operating and maintenance costs, which are quite high, transport and distribution costs of the diesel generator remains very high for a competitiveness of centralized-national network expansion scenario. Although few works are available on life-cycle analysis for adoption of

[21] In fact these two regions make up part of the region of Saloum, located in the middle- west of the country, are very similar in terms of climatic conditions, in contrast to the Thies region, situated in the northwest of the country.

renewable technologies in Sahelian countries, our conclusions are similar to those obtained by certain authors in regard to other developing countries. In conducting feasibility analysis for the adoption of renewable technologies in the case of Vietnam, Nguyen (2007) has shown the competitiveness of PV technology compared to conventional centralized-national network extension scenario. According to the same author, the competitiveness of the decentralized wind option depends on installation location. In analyzing the economic viability of the autonomous PV system in India, Kolhe et al (2002) conclude that: the PV system is comparable in economic terms to the diesel generator when demand is higher than 58 KWh/day with an equal discount rate of 10%. Similarly, Bugaje (1999) carried out a feasibility analysis of the adoption of energy technologies in Nigeria. As with the former example, three technological options were considered. The first consisted in performing extension of the electricity grid so as to provide electricity services to remote rural areas. Moreover, the two remaining options (PV and diesel group) guaranteed the supply of energy services via a decentralized autonomous process. His analysis demonstrated the viability of the PV system compared to the two remaining options with a distance of 50 km including all selected villages. Finally, Bhuiyan et al (2000) analyze the feasibility of the adoption of PV technologies in Bangladesh. Using the net present value methodology, their conclusions are identical to that found by all of the above-mentioned authors; the levelized-electricity- cost of PV energy is lower than that related to conventional sources in zones where electrical grid is non-available.

3.5: Conclusion

According to World Bank (2006), 1.6 million people in developing countries have not access to electricity. Anticipating the future, they predicted that a large portion of this population will lack electricity services if the same trends continue as exist now in terms of electricity distribution. While admitting a link between access to energy services and the improvement of living conditions, that means developing countries should wait long time before an improvement of their living conditions. Then one of the principal challenges facing developing countries can be summarized in two points:

- How could they increase electricity access particularly in remote rural areas
- Which electrification programme should they choose

The objective of this article is set within this background. We have attempted to compare two kinds of energy policy in one developing country (Senegal). The policy of autonomous decentralization via adoption of renewable energy technologies, and that of centralization leading to the extension of the electricity distribution network until the non-electrified zones. Three technological options were considered, namely a diesel generator with a capacity of 450 W representing the centralized option, a wind turbine with a capacity of 150 W and a PV module with a capacity of 130 Wc representing the decentralized scenario. After a life-cycle analysis evaluation, our results show the viability of the decentralized option of PV technology. Moreover, for wind technologies, the viability is compromised when the demand estimated is higher than their maximum capacity offered 7.47 KWh/year for Thies and 7.884 KWh/year for the two regions of Kaolack and Fatick. Our results demonstrated that the decentralized option using PV technology remains currently the most competitive solution for the satisfaction of energy demand in the context of small villages within the microgrids project scheme. This latter aiming to bring energy services to remote rural areas can intended different approaches within which the energy supply can be discriminate according to village sizes. Building a micro-network can be quite important for villages with a high population density located in the selected areas. This conclusion emphasizes what we know earlier, network has to be built in areas with high population density (ESMAP, 2007).

However, wind technologies may certainly present high viability in zones where wind speed remains fairly high, such as in the north (St. Louis). In this paper the low wind speeds involved the low level of production. The implementation of a geographical information system (GIS) would be a worthwhile initiative to produce a map of the wind speed of the country, allowing researchers to pinpoint zones where wind energy is viable. Moreover it is important to underscore that the results obtained depend heavily on a certain number of economic and technical hypothesis retained in this paper. For examples the rate of loss during electricity distribution, the structure of electricity distribution lines, and effectiveness of technologies utilized, escompte rate, and interest rate.

However although the renewable decentralized supply option to delivering electricity to remote populations in Senegal has shown its cost-competitiveness it would be interesting to analyze how such approaches could be finance within developing nations? The objective of the next paper is to investigate how the concept of the renewable energy premium tariff could provide an increase of the renewable technology promotion in Senegal. The concept of renewable energy premium tariff is chosen for two reasons. On the one hand, this mechanism is argued to stimulate the large promotion of renewable technologies in remote locations in developing nations (EC, 2008).

Therefore, our first reason is to provide an empirical verification of this assumption raised years ago by the European Commission. On the other hand, the selection of the renewable energy premium tariff is driven by the fact that there is no clear and well defined incentive approach promoting decentralized clean technology deployment in developing nations. Therefore, our investigation aims to provide notions and impacts of potential economic incentives promoting a decentralization of renewable technologies in developing nations. Finally our objective is to investigate price support for a market penetration of renewable technologies in developing nations.

Chapter 4: An energy pricing scheme for the diffusion of decentralized renewable technology investment in developing countries[22]

Abstract

The purpose of this paper is to investigate price support for market penetration of renewable energy in developing nations through a decentralized supply process. We integrate the new decentralized energy support: renewable premium tariff, to analyze impacts of tariff incentives on the diffusion of renewable technology in Senegal. Based on photovoltaic and wind technologies and an assessment of renewable energy resources in Senegal, an optimization technique is combined with a cash flow analysis to investigate investment decisions in renewable energy sector. Our findings indicate that this support mechanism could strengthen the sustainable deployment of renewable energy in remote areas of Senegal. Although different payoffs emerged, profits associated with a renewable premium tariff are the highest among the set of existing payoffs. Moreover in analyzing impacts of price incentives on social welfare, we show that price tariffing schemes must be strategically scrutinized in order to minimize welfare loss associated with price incentives. Finally we argue that a sustainable promotion of incentive mechanisms supporting deployment of renewable technology in developing nations should be carried out under reliable institutional structures. The additional advantage of the proposed methodology is its ability to integrate different stakeholders (producers, investors and consumers) in the planning process.

JEL: Q42; Q48; Q49

Keywords: renewable energy; developing countries; renewable premium tariff; renewable energy policies

[22] This chapter is a slightly adapted version of Djiby-Racine Thiam, 2011. An energy pricing scheme for the diffusion of decentralized renewable technology investment in developing countries, Energy Policy, 39, pp 4284 - 4297

4.1: Introduction

The cost-competitiveness of decentralized renewable technology in developing nations is strongly supported in the literature. The use of renewable energy instead of fossil fuels provides many advantages to developing countries (Chakrabarti et al 2002; ESMAP, 2007; World Bank, 2003; Evander et al, 2004; Karekezi et al, 2002). On the one hand, the promotion of renewable technology facilitates an increase of energy services in remote rural areas (Nguyen, 2007; Bugaje, 1999; Bhuiyan et al, 2000; Kolhe et al, 2002; Thiam, 2010a; World Bank, 2006; Kaufman, 2000; Martinot, 2001; World Bank, 2003). On the other hand, it provides important impacts on economic, environmental and social issues in developing nations. From an economic point of view renewable energy generation does not require fossil fuels for their operation, so fuel price variations affect neither the quantity of electricity produced nor the performance of the energy system. Their diffusion improves the local employment situation during the installation, operation and maintenance phases. From an environmental point of view, renewables technologies do not emit greenhouse gases (GHG) during the electricity production phase (Turkenburg, 2000; Owen, 2006) and their uses allow the reduction of health impacts on the population. In rural areas of developing countries, generated electricity from renewable sources could reduce the opportunity cost of biomass collection times (Heltberg et al,2000) and therefore the level of poverty by facilitating the achievement of Millennium Development Goals (MDGs) (Thiam, 2009; Zomer, 2003; Saghir, 2005).

In this context, many developing countries in sub-Saharan Africa encourage an increase of renewable energy through decentralized supply processes. For example some rural electrification agencies are created in order to increase the electrification level in remote areas. Their main functions are to develop and provide electrification programs for an increase of energy access in remote rural areas. Moreover they choose operators and attribute concession rights for any rural electrification scheme. Based on the substantial endowment of renewable resources in many African developing countries (Maiga et al, 2008; Karekezi et al, 2002), the investment in renewable energy is expected to generate a high level of clean energy output reducing the electricity access gap between urban and rural areas. Moreover, in rural areas where the lack of electricity is most problematic, women and children spend more than four hours per day on firewood collection (Thiam, 2009; World Bank, 2003; IEA, 2002; Karekezi et al, 2003; UNDP, 2000; Howells et al, 2005). This activity contributes to deforestation but also consumes time that could otherwise be used for development of other income-generating activities.

However, although one can agree on the cost-competitiveness of renewable technology in developing nations (Kolhe et al, 2002; World Bank, 2006; Kaufman, 2000; Martinot, 2001; World Bank, 2003), few studies have analyzed how incentive mechanisms could stimulate an increase of renewable energy under a decentralized supply option. The large body of existing literature has remained almost focused on incentive mechanisms in developed countries, particularly in Europe (Menanteau et al, 2003; Lauber, 2004; Meyer, 2003; Hvelplund, 2001; Mitchell, 1994; Neuhoff, 2005), where the European Commission made the goal of having 20% of the energy in the energy portfolio in 2020 come from renewable sources (EC, 2004). Most of the incentive mechanisms raised have been focused to assessing impacts of feed-in-tariff (FiT), renewable electricity portfolio standard (RPS) and renewable obligations (RO) on renewable energy promotion. To bridge this gap, the purpose of this paper is to analyze how an electricity tariffing scheme could encourage adoption of renewable technology in developing nations through a decentralization supply option. In doing so, we use an optimization technique to analyze the evolution of investment decisions in renewable energy under various energy tariff schemes. The latter incorporate the new renewable support mechanism being introduced in developing countries, namely the so-called renewable energy premium tariff (RPT). This tariff introduces a locally adapted variation of the FiT to encourage the production of renewable electricity in isolated areas of developing countries where grid extension remains financially unsustainable (Moner-Girona, 2009).

This paper is applied to the case of the developing sub-Saharan African country of Senegal for two main reasons. First, this country is representative of African developing countries in terms of investment ventures into energy. Second, within the framework of the diversification of energy supply the country is exploring the possible involvement of renewable energy into the energy supply portfolio. Furthermore, within the white paper dealing with the regulation of the energy sector it has been clearly highlighted the goal to increase the renewable share during the five-year period of 2008-2012.

The empirical analyses of instruments promoting adoption of renewable energy in African nation are weakly documented in the literature. Winkler (2005) discusses an instrument that could be potentially used in South Africa to promote diffusion of renewable technology. He differentiates between three mechanisms: a feed-in-tariff, the renewable electricity portfolio standards and renewable obligation. He argues that the selection of instruments must be guided by the policy objectives. For example when the objective is to promote renewable electricity, but budget constraints are prioritized, fixing price through a feed law would help minimize costs. Whereas when the objective is to promote an environmental quality, regulating quantities through a portfolio standard gives the greatest certainty to decision-makers. Wolde-Ghiorgis (2002) investigates possible policies to stimulate adoption of renewable technology in rural areas in Ethiopia. To promote renewable energy adoption, he proposes an increase of the budget allocated to activities associated with renewable energy promotion and a modification of the existing institutional framework. Chidiezie and Ezike (2010) suggest the requirement of political will and collaboration to promote deployment of renewable technology in Africa. To our knowledge Edkins et al (2010) provide the only research having empirically simulated impacts of renewable energy policies in Africa. They assessed the effectiveness of renewable energy policies in South Africa by assuming what could be the renewable energy produced if the REFIT[23] had been implemented earlier, before 2009 its starting period. They argue that based on the assumption that South Africa implemented a REFIT in 2005 the renewable electricity target of supplying 10,000 GWh by 2013 would already have been reached in 2011. On the basis of the existing literature, the contribution of the paper is, first, to provide an empirical investigation of the impacts of pricing mechanisms to stimulate adoptions of renewable technology in Senegal through a decentralized supply option. Second we analyze impacts of such pricing mechanisms on the social welfare.

The paper is organized as follows. Section 2 provides an assessment of renewable energy resources in Senegal. In section 3 we briefly provide a summary of common energy policies used to promote renewable technologies. Section 4 raises the main constraints faced developing nations while promoting renewable energy. Section 5 presents the methodology developed to simulate impacts of energy tariff schemes on the promotion of renewable technologies in Senegal. The results of the simulation are shown in section 6. The last section, section 7, concludes the paper.

Section 4.2: Assessment of renewable resource potential

The analysis of the potential of renewable energy resources is important for the promotion of an energy incentive tariff. The renewable resource map-making depicts areas where resources are more abundant in a region. This allows energy policy-makers to know areas where prices could

[23] Renewable energy feed-in-tariff

be moderated according to renewable resource endowments. The renewable resource assessment of Senegal is carried out under this framework. Studies analyzing the potential of renewable resources in Senegal are very few, although some researchers have argued that Senegal's substantial endowment of renewable resources has good potential for renewable energy development (Youm et al, 2000; Maiga et al, 2008; Thiam, 2010a). These conclusions remain mainly qualitative.

To analyze the renewable resource endowment in Senegal, we develop a geographical information system (GIS). The GIS assesses wind and photovoltaic (PV) resources in the country. The assessment of wind and PV resources follows two steps. First, the data on wind speed and solar radiation for all regions of the country are gathered. Then, the GIS is developed according to the available quantitative information. In the second step the areas assessed as having good resources of interest are depicted. The data on wind and PV resources are collected from the database of the National Agency of the Weather of Senegal. We collected wind speed and solar radiation data for all eleven administrative regions of the country. The wind speed is measured in m/s, whereas the solar radiation is measured in terms of (kWh/m2/day) in each area. For every variable of interest, we depict monthly values for a period of four years. Eleven regions – representing the defined administrative localities – are considered in this analysis. Our findings indicate that the real potential of wind resources in Senegal remains very limited compared to other sub-Saharan African countries. The area where such investment remains the most conceivable according to the well endowment of wind resources is the north-coastal region in general and the capital city of Dakar in particular with a wind speed averaging around 5 m/s (figures 1a; 1b).

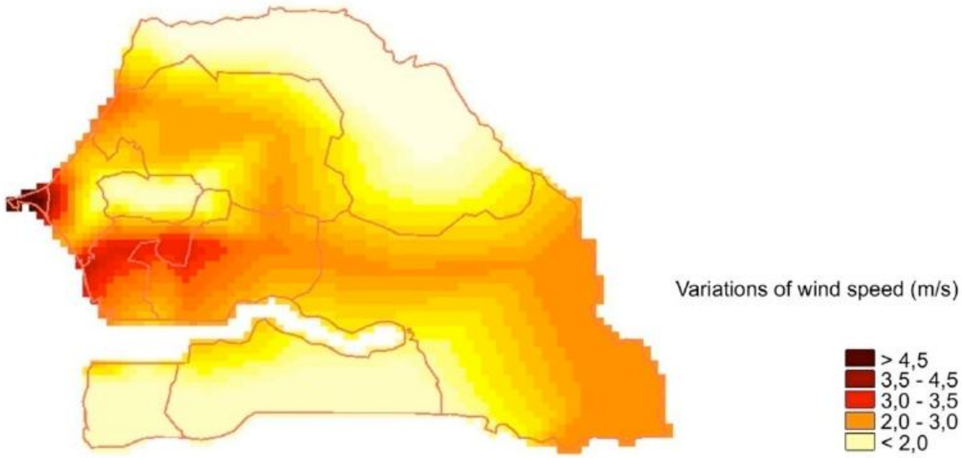

Figure 1a: Wind resource assessment of Senegal in 2008

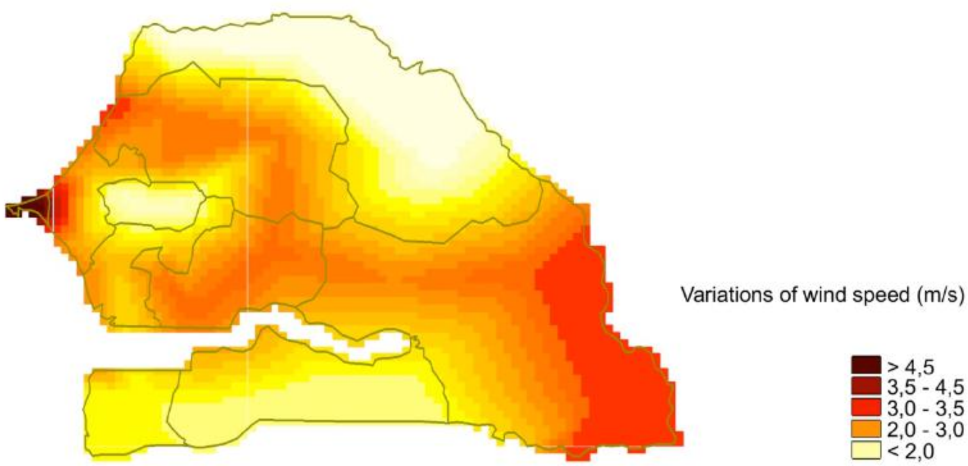

Figure 1b: Wind resource assessment of Senegal in 2007

For photovoltaic resources the country effectively presents a good endowment for solar energy development (figures 2a; 2b). The sun's radiation is very high despite its variation according to seasons, months and locations. For example, the radiation is higher in April and May than during the rest of the year. Furthermore, solar radiation is more geographically distributed than wind speed, which indicates that the solar decentralization is more resource efficient compared to wind energy.

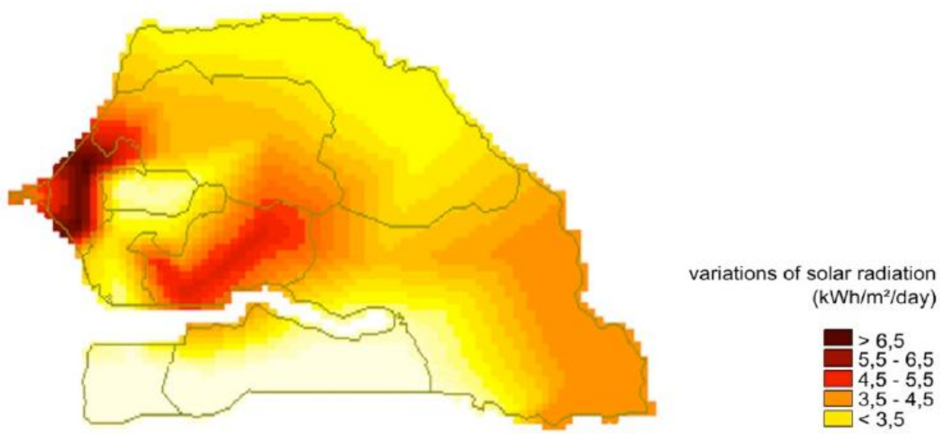

Figure 2a: Solar resource assessment of Senegal in 2008

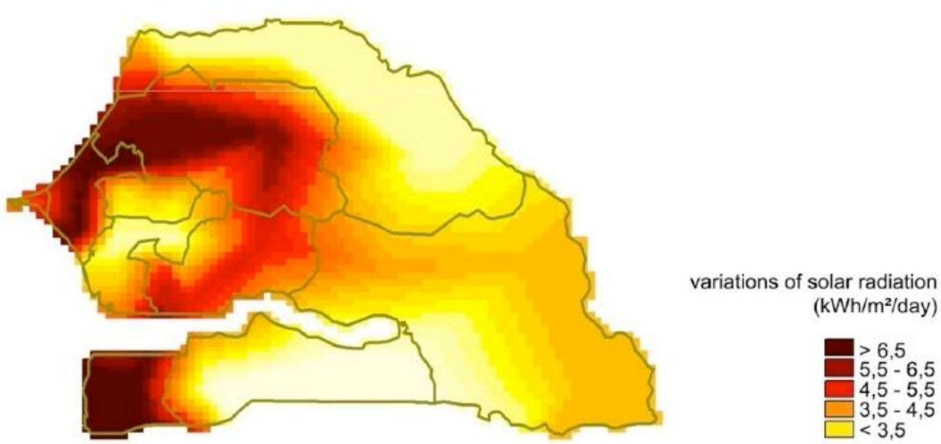

Figure 2b: Solar resource assessment of Senegal in 2007

Section 4.3 : Policies promoting adoptions of renewable technologies

The theoretical fundamentals of the promotion of renewable energy have two main objectives: the internalization of environmental externalities and the stimulation of technical change in the energy industry (Finon, 2006a, 2006b; Arthur, 1989; Menanteau et al, 2003; Foray, 1996). Such externalities are generated during the electricity production from fossil fuel resources. Generally, two types of mechanisms are used in order to promote renewable technology: "economic" (Jaffe et al, 1999) and "command and control" (Baumol et Oates, 1971) instruments. The economic instruments can include different forms, for example, tax policies, subventions and tradable permits. Whereas the command and control instruments referred to as standard or regulations, are used in order to promote renewable technologies. The choice of one instrument over other should reflect the objective of each country according to its priorities regarding environmental protection, economic development and socio-economic structure. Weitzman (1974) gives an important debate about the distinctions and the stakes of these instruments. Moreover, although some researchers have argued for the necessity to mix these two kinds of instruments two dichotomies appear in the literature in terms of the promotion of renewable energy: actions on price and actions dealing with quantities (Menanteau et al, 2003; Ackerman et al, 2001). One of the common actions dealing with price is the feed-in-tariff, such as that used in Europe (Germany, Spain and Denmark). Whereas instruments referring to quantity include the renewable energy portfolio standard that is currently used in the United States.

Unlike in developed countries, policies of renewable energy promotion in developing countries are carried out within the context of economic development and are still in an embryonic state. In the New Partnership for African Development (NPAD)[24] plan, the goal of diminishing the dependency on fossil fuel energy imports by the promotion of renewable energy generation has been highlighted. Moreover, in some African countries renewable targets have been established in order to increase the share of clean energy in the energy balance. Furthermore, although some incentives include a financial component, developing countries have means to support renewable

[24] The New Partnership for African Development (NPAD), created in July 2001, is the cross-country development plan between Senegal, South Africa, Algeria, Egypt and Nigeria. This scheme outlines ten main priorities that remain quite important for the development of African countries (http://www.nepad.org/2005/fr/home.php).

energy generation. As argued by Barnes et al (1998), rural people are willing and able to pay for reliable energy services. This finding indicates that financial barriers can be overcome when goods policies in favor of renewable energy promotion through a decentralized approach are created. For example, the policies used to strengthen the diffusion and development of renewable technologies in developing countries could eventually include the following (Evander et al, 2004):

- Changes in government regulations and guidelines or pricing and tariff policies
- Creation of finance mechanism
- Bulk procurement of energy efficient technologies
- Rebates and other consumer subsidies
- Public education and awareness campaigns
- Energy audits and the promotion of energy benchmarking schemes

However although instruments supporting deployment of renewable technologies in developing countries are not carried out as in industrialized countries it must be highlighted that for two to three years the shift to the market-oriented schedule of renewable energy deployment is aimed within numerous nations in Africa. This shift to a market-oriented of renewable technology in developing countries must be carried out while considering an improvement of energy governance[25]. The improvement of energy governance enables the more efficient involvement of institutional and political actors by for example, strengthening weights of local authorities and institutional hierarchies. Furthermore, improving energy governance encourages an involvement of local stakeholders (populations, end-users, consumers, producers) during the planning process. The involvement of these stakeholders allows the inclusion local constraints and socio-economic characteristics during decision processes, particularly in developing countries where a wide gap exists between rich and poor people. The failure to include these socio-economic characteristics leads to failure of most investment plan (Berkhout et al, 2003; Hisschemöller et al, 2004), particularly during a decentralized process that directly includes local end-users. The experience of the South African national electrification program can provide a good example to other sub-

[25] Energy governance requires a coordination effort and changes among many different actors, institutions and artefacts (Unruh, 2002; Elzen et al, 2004; Smith et al, 2005) for the success of any energy planning scheme.

Saharan African countries. South Africa has created a national electricity supply commission that coordinates all electricity investment in the country and to preventing inefficient investment (Steyn, 1995). In addition to reliable energy governance, adequate renewable energy policies must be promoted according to constraints of each country. Before exploring specificities of developing nations during a promotion of renewable energy existing renewable energy policies in various countries are provided.

4.3.a : Feed-in-tariff

The feed-in-tariff (FiT) scheme implies a certified purchase by utilities of electricity produced in defined areas from renewable technology at a fixed tariff during a certain time. The feed-in-tariff is defined by the government and reflects the price of electricity in kWh that the local company pays to the renewable energy producer. Because various renewable technologies have reached different stages of maturity (Christiansen, 2001), the feed-in-tariff should be defined for each technology to avoid handicapping some technologies (Finon, 2006a; 2006b). Moreover, the feed-in-tariff depends on the capacity of the renewable energy generation system. It reflects subsidies provided to producers, which equals the difference between the cost of renewable electricity produced and the current electricity price. The feed-in-tariff has been highly successful in Germany, where the feed law has enabled an increase of renewable energy production (Butler et al, 2008; Jackson et al, 2000). However, the implementation of a feed-in-tariff requires knowledge of the marginal cost curve of electricity generation (Menanteau et al, 2003). Although in developing countries the determination of the marginal cost curve can be criticized, fixing the feed-in-tariff provides good security to developers of renewable energy and follows the principle of "transactional efficiency". Finon (2006b) defines the main aspect of transactional efficiency in two parts. The first part is the investors' need to secure a long-term investment plan by a very reliable contract guaranteed according to the agreed-upon quantity to be purchased. In addition, instruments should offer credibility to renewable energy investors and manufacturers' plant building, if the building process takes place in national areas.

4.3.b : Renewable obligation

In the case of renewable obligation (RO), the government sets targets of renewable energy to produce during a fixed period. Then, the government allows the potential clean energy suppliers to compete for the supply of the renewable energy. The selection process is carried out within a bidding context, and the lowest priced option is chosen (Menanteau et al, 2003; Ackerman et al, 2001). Once a producer is selected at the corresponding price, a contract is set up between two parties guaranteeing payment to the selected producer at the fixed price. This process was applied in the NFFO[26] program in the UK in 1990 to promote the diffusion of renewable energy (Butler et al, 2008). Indeed, this instrument requires institutional reliability between parties because terms of contracts must be honored. Therefore, once litigation begins, it must be carefully arranged by legal institutions without being influenced by public power.

4. 3. c : Renewable energy portfolio standard (RPS)

The renewable energy portfolio standard remains quite similar to the renewable obligation instrument, as the government fixes the share of renewable energy to produce in the energy portfolio during a fixed time period. This instrument is argued to be more efficient than the renewable obligation (Menanteau et al, 2003) because the competition between renewable technologies is not stimulated by the energy policy. However, as Finon (2006a) argued, the functioning of this kind of instrument requires a large number of rule and institutions that create high administrative and ex-post negotiating costs for the assessment of the instrument and its adjustment by public authority.

Section 4.4: The right compromise for renewable energy support in developing countries

These preceding instruments are focused on two main principles: actions on prices (feed-in-tariff) and actions dealing with quantities (RPS and RO). Moreover, it must be highlighted that

[26] The non-fossil fuel obligation (NFFO) was administered as a series of competitive orders for which renewable energy developers submitted bids specifying the energy price at which they would be prepared to develop a project (Butler et al, 2008).

most incentive mechanisms raised to promote deployment of renewable energy are carried out in developed countries. The large renewable portfolios in many developing countries followed a process-oriented approach and the clean development mechanism[27] (CDM) remains the most investigated international renewable promotion commitment focusing on renewable energy development in developing countries. However, the emergence of the new concept of market-oriented of renewable energy in developing countries necessitates the analysis of instruments for the promotion of clean energy. The choice of an adequate instrument should follow a nation's priorities because each instrument possesses advantages and drawbacks. The analysis of instrument efficiency can be summarized according to two objectives: the supplement of renewable technology capacity installed and the evolution of renewable energy prices (Butler et al, 2008). Moreover, it is important to highlight the fact that the price mechanism support requires a good management plan and a sustainable partnership between developing countries and some international organization. Many developing countries are obliged to borrow investment funds from international organizations - for example, the World Bank or the International Monetary Fund - which have their own financial conditions according to the institutional profiles[28]. Their financial conditions could be a difficult obstacle for a deployment of renewable technology. Moreover, there are many others factors affecting the development of renewable energy supply.

[27] The CDM is a project-based mechanism under the Kyoto Protocol according to which certified emission reductions (CER) is generated through projects in non-Annex-I countries. These CERs can be bought and used by Annex-B countries to meet their emission targets as specified in the Protocol. An important rationale behind this concept is the fact the GHG emission reductions are generally less costly in developing countries than in industrialized countries.

[28] The institutional profile captures the reliability of political institutions and safety, public order, violence control, operations of public administrations, operation of the national market, actor coordination, strategic visions, innovations, reliability of contrast transactions, market regulation, social dialogues, social cohesion, social mobility, etc.

For example, the figure 3 shows the interconnections of factors affecting renewable energy promotion.

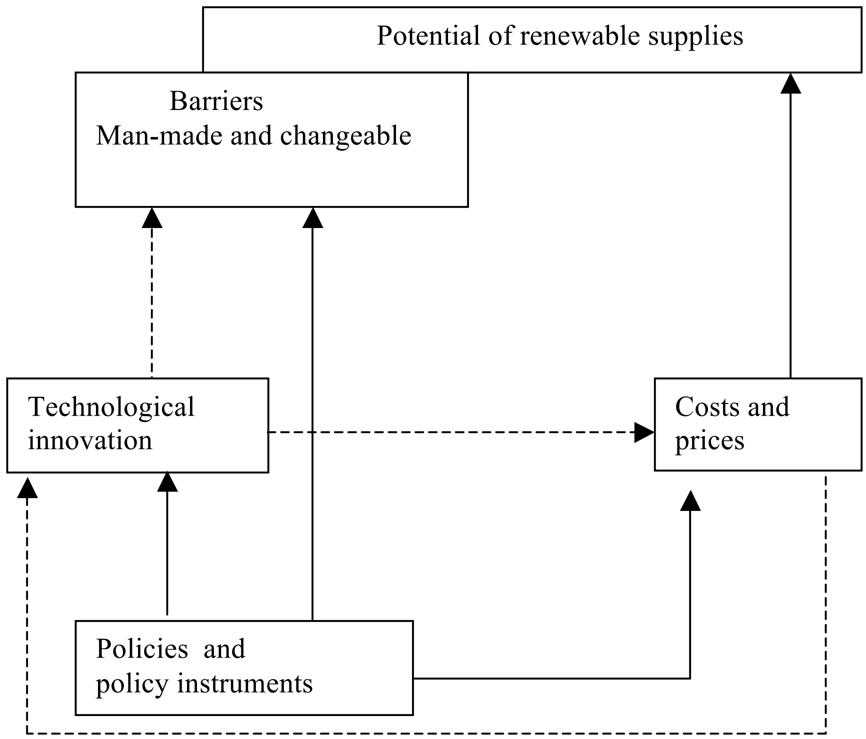

Figure 3: Factors affecting renewable energy supplies.
Source: Verbruggen et al., (2010)

Furthermore, an important point that remains crucial regarding the investment issue in sub-Saharan developing countries is the political and social structure. Investing in renewable technology requires strong institutional reliability. Even if a country has a well-structured institutional hierarchy, it must deal with problems relating to corruption and bad governance to increase the attractiveness of private investment. The most recent classification of the most corrupted countries around the world placed Senegal in the 71st position in more than 170 countries (Transparency International, 2008). Furthermore, the technology selected should also be socially accepted by local end-users. Many studies have argued that local social constraints is a blocking factor of the diffusion of renewable technologies (Wüstenhagen et al, 2007; Mallett, 2007; Michalena et al, 2009; Araujo et al, 2008; Eskom, 2006; Sauter et al, 2007; Wamukonya, 2007). This point remains a crucial aspect for the investment under a decentralized option as that scheme is conducted mainly in rural areas, where populations have their own habits and sometimes remain resistant to change. As Lu (2005) argued, the social acceptance of technology can be guided by two driving forces: the instrumental beliefs such as perceived usefulness and perceived ease of use as drivers of usage intentions and the technology characteristics as major external stimuli of the adoption.

However, even if the renewable energy support in developing countries remains weaker than in developed countries, it must be highlighted that some developing countries encourage regulatory and financial arrangements for the development of renewable technology. For example, South Africa is among the first sub-Saharan African country to having implemented the feed-in-tariff scheme in 2009. Moreover, in addition to the South African case others African developing countries - Senegal, Tanzania, Uganda, and Mali - have subsidy policies supporting an increase of the rural electrification level from renewable technologies (Moner-Girona et al, 2008). In all of these countries, a legal framework exists for the development of renewable technology.

4.4.a : Renewable premium tariff

The urgent need for an insight promotion of renewable energy coupled with the local geographical disparity of populations in African developing countries have led to a new theoretical instruments supporting the decentralization of renewable technologies in developing nations. This measure introduces a locally adapted variation of the feed-in-tariff to encourage the decentralization of renewable technology in isolated areas of developing countries where grid extension remains financially unsustainable (Moner-Girona, 2009). Moreover, as Moner-Girona et al (2008) argue, the deployment of the renewable energy premium tariff (RPT) in developing countries could probably encourage, in the long-term, an increase of the share of renewable energy into their energy balance. RPT is a tariff mechanism adapted from the FIT in order to guarantee secure payoffs to energy producers in developing nations. It represents a tariff instrument added to the clean energy price to increase the investment capacity in developing nations. For example the figure 4 shows how the price modularity allows an increase of a capacity generated in a market. Where P_m, P_M and P_e represent the minimum, maximum and equilibrium prices respectively. P_i and Q represent the current price and the quantity of renewable electricity respectively.

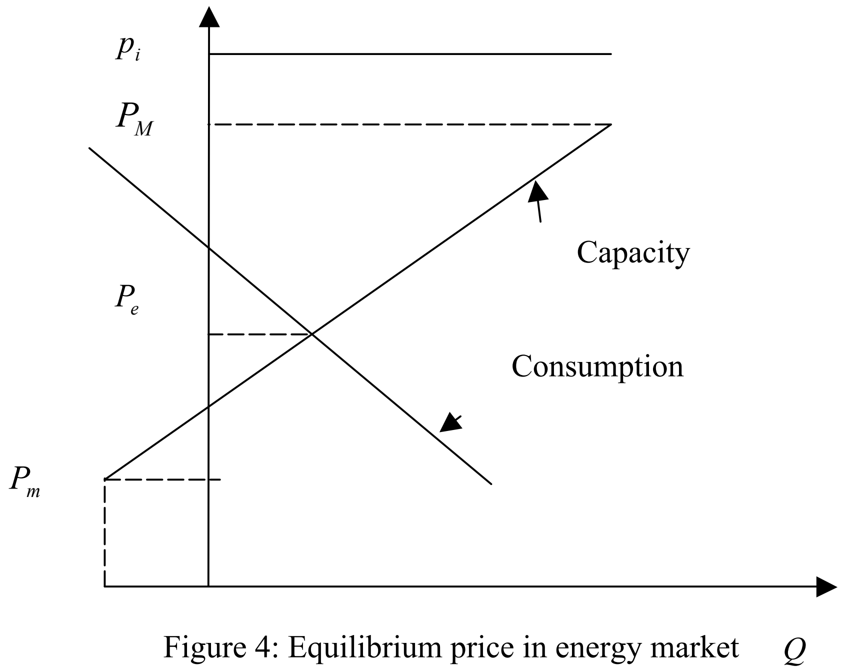

Figure 4: Equilibrium price in energy market

Moreover it is important to highlight that policies promoting renewable technologies are not completely transposable from one country to another (for example from industrialized to developing nations), because the type of financial mechanisms stimulating a deployment of renewable technologies could vary between countries. For example such financial mechanisms can be conditioned by a market size of energy sector, a geographical distribution of populations, a level of technological innovation etc. For example figure 5 shows the existing financial mechanisms usually carried out by developing nations to promote renewable technologies through a decentralized process. Figure 6 shows the framework of renewable premium tariff under the independent power production regulatory scheme.

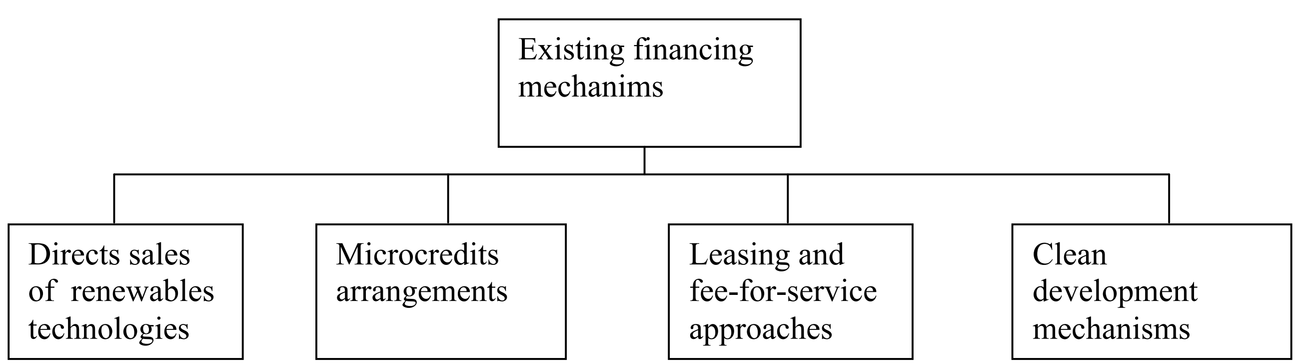

Figure 5: financial mechanims for the decentralized renewable technologies

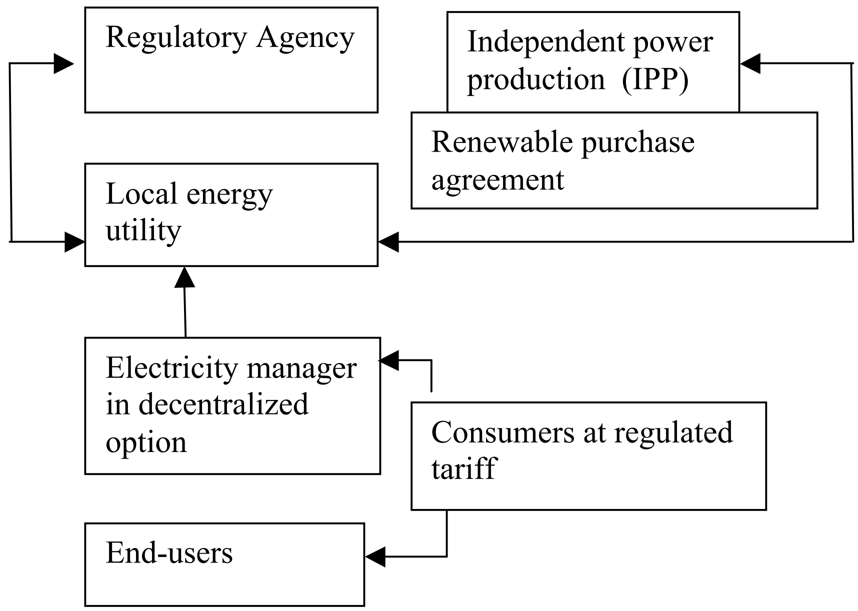

Figure 6: IPP regulatory framework under the RPT scheme for off-grid electrification support
Sources: Moner-Girona, (2009)

Section 4.5 : Methodology

An end-oriented optimization method has been carried out to analyze the impact of energy policy on the development of renewable technology. The model provided is composed of two steps. First, an optimization technique is used in order to determine the amount of renewable energy consumed. This value is then used in a net present value (NPV) approach to analyze investment decision. The model differentiates investor from consumer prospects. In the investor prospects, decisions to invest are guided by the expected profit. The long-term equilibrium is realized once the investor surplus (which is the difference between revenues and relevant costs) is equal to zero for all required renewable technologies. The model considers two types of renewable technologies namely photovoltaic and wind technologies. In our model, an increase of electricity prices, all things being equal, stimulates an increase of the expected outcome of the profit. Whereas an increase of relevant costs of renewable technologies decreases the profit. These costs include fixed costs, which represent all costs relating to installation and engineering costs, and variable costs, which remain relevant to the electricity produced. The consumer prospect is evaluated through a maximization of their surplus. We assume that the consumer determines his (her) energy demand while knowing the constant energy price. The strength of this methodological approach is its ability to include different stakeholders (i.e producers, investors and consumers) during the process of renewable technology promotion. Figure 7 shows the framework of the methodology developed in this paper.

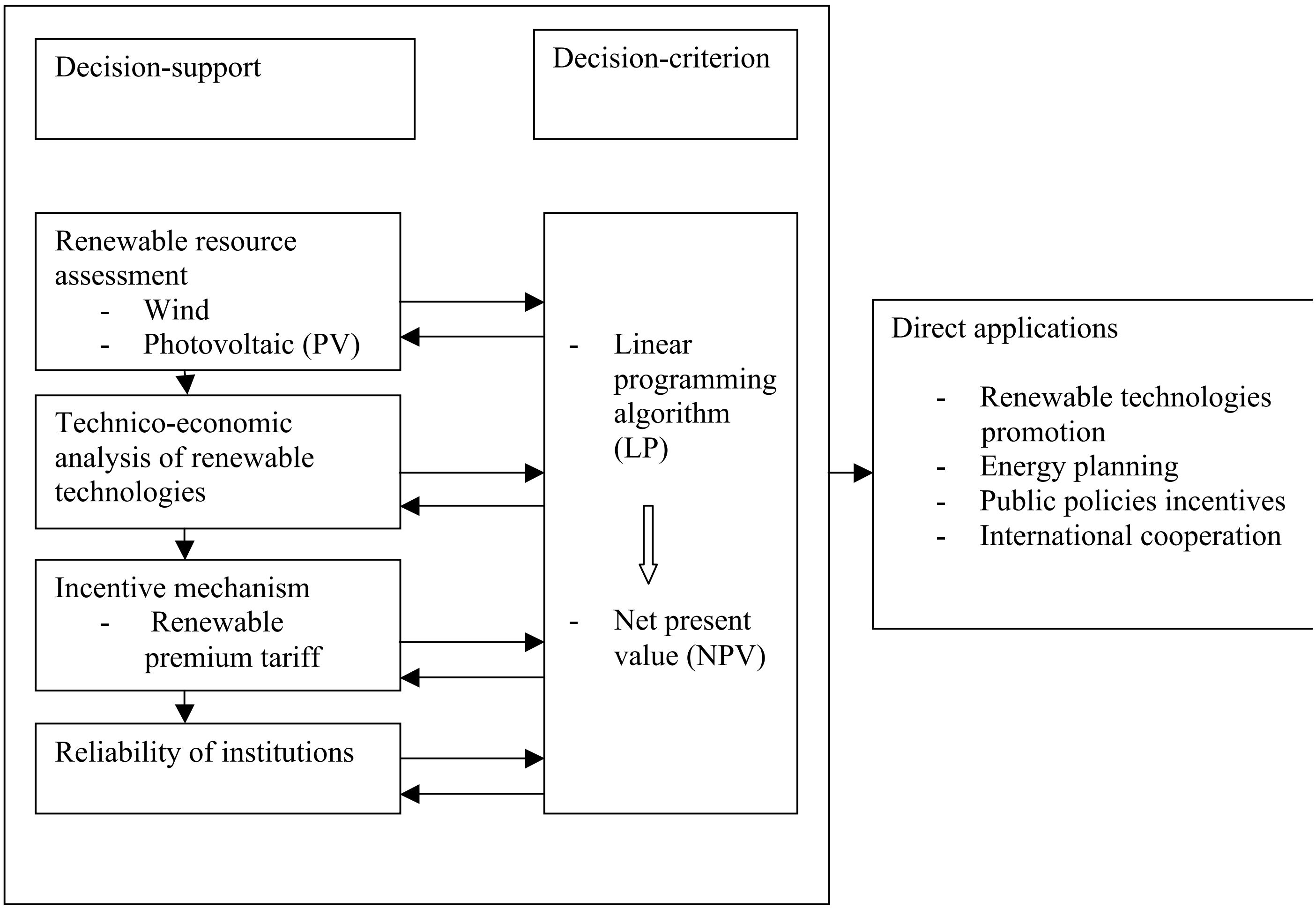

Figure 7 : Framework of the model

4.5.a : Investor prospect

In the model, the investment in renewable technologies depends on the expected evolution of the profit. The objective of the investor is to maximize the profit. Equation (1) assumes that the profit of the investor is the difference between revenues (pq) coming from the sale of renewable energy produced and the costs $(\alpha q + \beta X)$ associated with the production of such energy. These costs are constituted by the sum of fixed costs (βX), which are independent of the renewable energy generated and variable costs (αq), which depend on the energy supplied.

$$\Pi = (pq - \alpha q - \beta X) \quad (1)$$

Where p and q are the current price of energy and the renewable energy produced, respectively. The terms α, β and X are, respectively, the unit variable costs, the unit cost of capacity of renewable technology installed for the satisfaction of energy demand. The fixed costs include all costs covering installation and engineering costs, and the variable costs represent costs that vary as a proportion of the level of energy production. Considering photovoltaic and wind technologies the expected payoffs of the investor can be rewritten in the following form:

$$\Pi_P = pq_p - \alpha_p q_p - \beta_p X_p \quad (2) \qquad \text{with } \alpha_p = \alpha_w$$

$$\Pi_w = pq_w - \alpha_w q_w - \beta_w X_w \quad (3) \qquad \beta_p \succ \beta_w$$

where the indexes p and w denote photovoltaic and wind technologies, respectively. Therefore, $\prod_p$ and $\prod_w$ are profits under solar photovoltaic and wind investments, respectively. The variables q_p and q_w are, respectively, the energy produced from solar photovoltaic and wind technologies. The coefficients α_p, α_w, β_p, and β_w are the unit variable cost and the united fixed cost of photovoltaic and wind technologies. We assume that the unit variable cost of the selected technologies are identical[29] and that the unit fixed cost of wind technology is less than the photovoltaic unit fixed cost according to the steep increase of the experience curve[30] for wind[31] compared to solar photovoltaic technologies. The variables X_p and X_w represent the total installed capacities of solar and wind technologies, respectively.

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[29] This assumption has been made to simplify the analysis.

[30] The phenomenon of experience curve has been originally observed in the field of Aeronautic by Wright (1936) before the second word war. This idea has been translated in Economics by Kenneth Arrow since 1962 in his seminal paper "The Economic implications of learning-by-doing" published in "Review of Economic Studies. The theory of experience curve expresses the reduction of a technological cost following the cumulative production (cumulative in terms of capacity installed or output generated)

[31] This assumption follows the current trend of costs of wind compared to other renewable technologies (including solar photovoltaic technology). It is shown (IEA, 2008) that wind technologies are most cost-competitive compared to photovoltaic ones.

4.5.b : Consumer prospect

The objective of the consumers is to maximize their surplus. In this paper we assume a representative consumer, therefore we have considered a surplus for one consumer. With one consumer, the surplus can be represented in the following terms:

$$Z = c(q) - pq \qquad (4)$$

where Z represents the surplus of one consumer, q the current electricity consumption, $c(q)$ the willingness to pay to by q such as $c(q) = \int^{q} p(x)dx$ with $p(x)$ the willingness to pay for the xth unit of q and pq representing the market cost of energy consumed. The objective of the representative consumer is to maximize his surplus. As mentioned above, the consumer determines his energy demand while knowing the constant energy price (p). This assumption is made in order to simplify the resolution of the model. Therefore, the surplus of the consumer in the long-term can be rewritten in the following terms:

$$Z = c(q) - pq \qquad (5)$$

In equation 5, the first derivative condition allows us to write the equation 6

$$\frac{dZ}{dq} = \frac{dc(q)}{dq} - p = 0 \qquad (6)$$

Once we determine the willingness to pay for electricity $c(q)$, we could easily determine the demand curve from this preceding equation. The willingness to pay is determined by resolving the equation (6) and once postulated the functional form of the electricity demand as a function of price p namely $q = q_0 \left(\frac{p}{p_0} \right)^{\delta}$ (see appendix A)

$$c(q) = c_0 + \frac{p_0 q_0}{\mu} \left\{ 1 - \left(\frac{q_0}{q} \right)^{\mu} \right\} \qquad (7) \qquad \text{with} \qquad C_0 = c(q)$$

where $\mu = -(1 + 1/\sigma)$ (8)

where c_0, p_0 and q_0 are constant terms and σ is the elasticity of the electricity demand[32]. The constant terms represent initial values of the solution of the differential equation (6). Therefore, the objective of the consumer is to maximize his surplus under the following constraints:

$$\begin{cases} q_w \leq q \leq q_w + q_p & (9) \\ \sum_{i=1}^{I} \frac{X_i}{s_i} = \frac{X_w}{s_w} + \frac{X_p}{s_p} & (10) \end{cases}$$

where s_i represents the variable measuring the social acceptability of new renewable technologies. X_i represent the installed capacity of renewable technology i with $i = w, p$. We assume that the energy required is at least higher than the physical potential of wind energy according to the weak endowment in wind resources in Senegal as evidenced by the GIS. From a mathematical point of view, as represented in equation (9), such an assumption means that the energy consumption q is higher than the energy provides by wind technologies q_w. But it remains lower or equal to the sum of the existing renewable energy $(q_p + q_w)$ provided by both solar photovoltaic and wind technologies. As our model includes only two types of renewable technologies, it is physically impossible to generate more energy than the total energy produced from wind and solar PV technologies. The constraint (10) assumes that the sum of the renewable energy provided is balanced with the installed capacity and a coefficient measuring social acceptability of renewable technologies. This constraint indicates that the real capacity of the technologies takes into account the willingness of both consumers and producers to promote renewable technology deployment. Such willingness is driven by their sensitivity in environmental qualities. One could remark that a large value of s_i, corresponds to a high environmental sensitivity of consumers and producers while a low environmental sensitivity

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[32] The elasticity is a coefficient that relied two relative marginal variations $E\left(q/p\right) = \frac{d\ln q}{d\ln p}$ therefore $\frac{dq}{q} = E\left(q/p\right)\frac{dp}{p}$

corresponds to a low value of s_i. The constraint (10) shows also that this assumption is made for all existing renewable technologies. Otherwise, we consider a social acceptability of all selected renewable technology with *I* representing the maximum number of renewable technologies considered.

4.5.c : Energy investment model

The impact of the energy tariff on the investment decision is evaluated under the Net present value (NPV) criterion. The current rule argues that the decision to invest depends on the sign of this variable. If it is positive - indicating no presence of uncertainty - the investor can invest, but he should choose not to invest when it presents a negative value. The determination of the NPV requires information on income, values of electricity generated using renewable costs and technical data on renewable production.

- *Income*

Income is directly relevant to the framework of an energy tariffing. The formula for the determination of income is as follows:

$$Income = pq \qquad (11)$$

where *p* represents the electricity price during the lifetime of the project and *q* the quantity of electricity produced by the renewable technology considered. The determination of the production quantity *q* is performed by the engineering methodology proposed by (Nguyen, 2007). Moreover we assume that all the electricity production is sold.

- *Renewable production*

The determination of renewable energy is carried out under meteorological conditions of Senegal. Moreover, in the context of photovoltaic technologies, production depends on the surface utilized, nominal power of the module and the daily rate of radiation. According to (IE, 2000), the production of electricity from photovoltaic technology can be estimated using the following equation.

$$q_p = \gamma_p \times X_p \times \frac{b_r}{b_{0r}} \times 365 \qquad (12)$$

where X_p is the maximum capacity installed of the photovoltaic unit, b_r represents the annual average rate of solar radiation in a given region and b_{or} the rate of radiation standard for each region measured in (kWh/m2/d), γ_p the efficiency of the PV system and 365 is the number of days per year. In the case of wind technologies, the energy produced varies according to wind speed cubed. Moreover to determine the quantity of energy produced a good knowledge of wind speed distribution is required. The Weibull function permits determination of the distribution of the speed. Following Nguyen (2007), the distribution function can be represented as follows:

$$f(v_r) = \frac{\pi v_r}{2(v_{mr})^2} \exp\left(\frac{-\pi}{4}\right)\left(\frac{v_r}{v_{mr}}\right)^2 \qquad (13)$$

where v_{mr} represents the average wind speed (m/s) for each region considered and vr the speed for each year under each given region. From the above equation, annual energy production can be calculated according to (IE, 2000) using equation (14):

$$q_w = \sum_{t=1}^{T} \gamma_w \times f(v_r) \times p(v) \times 8760 \qquad (14)$$

where *P(v)* represents the power of the turbine, the probability density of the Rayleigh function[33] is represented by $f(v_r)$, γ_w represents the efficiency of the system and 8760 is the number of hours per year.

- *Costs*

The costs considered in the context of investment in renewable technology are the sunken capital cost, the operating and maintenance costs and the replacement cost. All of these costs are considered on their discounted value.

Capital cost

Capital costs are those linked to the purchase of all system components, such as generators, PV units and batteries. They are generally defined as the initial acquisition costs for equipment before installation begins. These costs are exogenous. The capital cost are represented by c_c

33 The Rayleigh function is the value of the Weibull function when the charge factor is equal to two (Nguyen, 2007).

Operating and maintenance cost

Within a long-term perspective, technologies employed must include maintenance costs. These costs vary according to the types of technologies selected. This expense is low for renewable technologies as compared to conventional technologies.

$$C_m = AnnC_m \left\{ \left(\frac{1+i}{r-i} \right) \times \left[1 - \left(\frac{1+i}{1+r} \right)^N \right] \right\} \qquad (15)$$

Where *i* represents the inflation rate, *r* the discount rate, *AnnCm* corresponds to annual operating and maintenance cost, and finally, *N* represents the number of years considered.

Replacement cost (C_R)

This represents the costs involved in the replacement of certain system components that have a shorter lifetime than that of the project. They can also include replacement costs related to wear and tear of certain devices.

$$C_R = \sum_{j=1}^{V} \left\{ item\cos t \times \left(\frac{1+i}{1+r} \right)^{N_j} \right\} \qquad (16)$$

where N_j represents the life-time of the replacement of technology j, with the condition $N_j \prec N$. This assumption indicates that the technology must be replaced before to achieve the full lifetime of the project.

Regardless of the above information, the decision to invest is made based on the sign of the net-present value function:

$$NPV = \sum_{t=1}^{N} \frac{CF_t}{\left(\frac{1+r}{1+i} \right)^t} - \left(C_c + C_m + C_R \right) \qquad (17)$$

where $CF_t = pq$ and $q = q_p$ or $q = q_w$

where CF_t, C_m and C_R are the total cash flow, operating and maintenance and replacement costs respectively.

In our basic setup, we assume that there are only two alternative investment projects, either wind technology or photovoltaic panels. Therefore, the NPV is for wind and solar PV technologies. Time is discrete and the decision-maker can invest in one of the two projects. The output of each project depends on the capacity of the selected technology and the endowment of renewable resources. The decision to invest is certainly guided by the sign of the net present value, which relies directly on the trend of the energy tariff. According to this price, the investor decides whether or not to mobilize the investment. Then, the decision to invest is given by

$$NPV = V(p) = \max ..\{V(P_j),.....P \geq 0\} \qquad (18)$$

where V(p) represent the NPV of the investment. This value follows trends of energy prices. $V(p_j)$ represents the value of the investment when $p = p_j$. Here also a high (low) p generates, respectively, a high (low) investment value as long as associated costs remain constants. The equation (18) shows that investors will always select the maximum among existing investment values. A maximum value of $V(p_j)$ correspond to the maximum of existing payoffs.

4.5.d : Case study

As indicated earlier, the case study focuses on the developing country of Senegal. The data considered remain primarily focused on the structure of renewable devices in this country (table 1). Ti, in the first column of table 1, represents the technology. *Xi*, in the second column of table 1, represents the capacities of renewable technologies, which vary between T*i = 5* and T*i = 25.* Therefore, we provide in the second column of table 1, different technologies corresponding to each renewable technology. The capacities are measured in kilowatt (Kw) and represented by X*i*. The third and fourth columns represent the capital costs of both wind and solar photovoltaic technologies. One can remark, as mentioned above in the footnote 9, that the capital cost of photovoltaic technology remains much higher compared to the capital cost of wind technology. The capital costs are measured in dollar per kilowatt ($/Kw). The capital costs of wind and solar photovoltaic technologies are, respectively, represented by Kw and K*p*. The last column of table 1 represents the operating and maintenance costs of wind and solar photovoltaic technologies.

We assume that these selected renewable technologies require the same operating and maintenance costs. Moreover, it is argued that the running maintenance costs of renewable technologies remain very small compared to fossil fuel technologies requiring fuel costs and complex maintenance. The operating and maintenance costs are represented by Om*i*. Table 2 shows the other specific data requires to calibrate the model. The first four lines show respectively, the interest and discount rates and the efficiencies of wind and solar photovoltaic technologies. The lines 5 and 6 show indexes measuring social acceptability of renewable technologies. The last line shows the initial values of the model. These specific data are selected from different sources in the literature (for example the Ministry of Energy, Energetic Information System of Senegal; World Bank).

Table 1: Technical and economic features of selected devices

Technologies (Ti)	Xi (KW)	Cw ($/KW)	Cp ($/KW)	OMi ($)
T1	5	2500	3700	0.05
T2	10	2500	3700	0.05
T3	15	2500	3700	0.05
T4	20	2200	3500	0.05
T5	25	2200	3500	0.05

- Source: Compiled by the author based on interviews with local renewable technologies distributors
- The terms Ti, Xi, Cw, Cp and Omi represent the selected types of renewable technology, the initial capacity installed of wind and PV, the capital cost of wind technology, the capital cost of PV technology and the annual operating and maintenance of the selected technologies respectively. We referred to US $.

Table 2: Technical and economic characteristics of selected technologies, values are in percentage

Interest rate	i	3
Discount rate	r	3.5

Efficiency of PV	γ_p	0.78
Efficiency of wind	γ_w	0.78
Social acceptability of wind	S_w	1
Social acceptability of PV	S_p	1
Initial values	$C_0 = p_0 = q_0$	1
Elasticity-price of the energy demand	σ	- 0,5

- Sources: compiled by author based on various sources (Ministry of Energy of Senegal; Energetic Information System; World Bank.)
- We assume an inflation rate and a discount rate of 3%, 4,5% respectively as recommended by the Central Bank of West African States.

Furthermore, as technology diffusion is highly relevant to social acceptability, we assumed that the social acceptability of these new technologies is complete. All habitants are ready to participate in an energy substitution that will reduce their dependency on fossil fuel energy, protect the environment and enable the energy transition[34]. In this paper, we do not emphasize the distinctions between socio-political acceptance, market acceptance and community acceptance as argued by Wüstenhagen et al (2007). We assume that the acceptance is exogenous and that all consumers are ready to change their energy behavior for more efficient energy use, therefore $s_w = s_p = 1$. As indicated earlier, two kinds of renewable technology are investigated, namely photovoltaic (PV) technology and wind technology. PV modules produce electricity by directly converting the sun's rays into electricity. The electricity produced is delivered in the form of direct current (DC), which is useful for numerous applications. However, a transformation to alternating current (AC) is necessary if the electricity generated is to be introduced into a distribution network. The energy provided by the module depends on its surface area, nominal power of the panel and duration of sun exposure. The latter varies according to latitude, season, and time of day. Moreover, taking into account the intermittent characteristics of renewable sources (Menanteau et al, 2003; Owen, 2006), the majority of photovoltaic (PV) modules not connected to the distribution network use batteries. The batteries allow storage of energy supply during periods of variable meteorological conditions while also enabling equilibrium between energy supply and demand. In rural areas of developing countries, this type of technology is highly appropriate for responding to the energy needs of the population (Karekezi et al, 2003). In the case of wind turbines, kinetic energy is converted into mechanical energy or electricity via the rotation of the turbine. The power captured by a wind turbine is a function of the square of its diameter and the cube of the wind speed. When favorable meteorological conditions exist, wind technologies represent a good alternative method of supplying electricity. Although more costly compared to conventional technologies the costs associated with renewable technologies have come down significantly during the last few years. Advances in research and development and the emergence of the assembly market in developing countries have lowered the cost of renewable technology units. In this paper, we perform a scenario analysis to simulate impacts of renewable premium tariff on energy investment under a decentralized supply option. The

[34] The energy transition reflects the change in energy resource consumption. For example the substitution of biomass energy by wind or solar PV energy.

scenario developed in this paper is focused on three kinds of energy policy tariffs namely the marginal cost, the average cost and the renewable energy premium tariffs. The latter follows mainly laws passed in parliament that remain substantially modified by decree legislations. The length of the contract varies between ten and fifteen years according to the country's priority on renewable energy promotion. By analogy to feed-in-tariff the RPT assumes that the local government provides to renewable producers a RPT scheme including a renewable energy purchase agreement. This scheme can be carried out in the context of a regulated situation or in the context of liberalization. In the first case, a regulatory agency is created with the aim of offering a regulatory RPT framework to a private sector producing renewable energy according to the government's priorities. In this framework, only the selected private firm could provide energy (Moner-Girona et al, 2008). If the RPT is applied in the liberalized context, competition takes place enabling competing renewable energy producers to offer a lowest-cost option for the production of renewable electricity.

However, as the structure of the RPT scheme is directly derived from that of FiT the adequate contract length should be between 10 and 15 years. During this period, a contract is built between the utility and the renewable investor guaranteeing the purchase of the entire amount of renewable production during this period of time. In this paper we assumed that the contract length is a fifteen-year RPT. To determine the adequate value of RPT we determine the threshold value below which no investment in renewable technology is carried out. We assume that a developer can choose from among six different modules (T*i*) with capacities *Xi* and associated capital C_c and operating and maintenance costs C_m.

Section 4.6 : Results

The results of the analysis illustrate the evolution of surpluses and decisions to invest in renewable energy in relation to price policy evolutions. We differentiate between surpluses of consumers and surpluses of producers (the profit). Moreover such surpluses are represented for each energy tariff incentive: marginal, average and renewable energy premium tariffing schemes. Figure 8 shows the outcome of our simulation. Surpluses are represented by S1, S2 and S3. S1 is the surplus under the renewable energy premium tariff scheme while S2 and S3 represent surpluses under average and marginal cost tariff schemes, respectively. Our results show that for the producer of renewable energy, the surplus is higher under the renewable energy premium tariff. Moreover, although lower compared to renewable energy premium tariff, his (her) surplus still remains positive under the average tariffing scheme. When marginal tariff structure is applied, the surplus of producer becomes negative as evidenced by the figure 8. For the consumer, the surplus is higher under the marginal cost tariff. For both renewable energy premium and average tariff schemes, surpluses of the consumer become negative. Our results show that the investment in renewable energy under decentralized supply options depends on the nature of the energy tariff policy and the level of price retained. We conclude that the best way to stimulate an increase of renewable technologies promotion in a decentralized process is to adopt an incentive mechanism that guarantees producers a secure long-term income. Our result confirms the theoretical stance taken by European Commission since 2008. The European Commission argued that the adapted feed-in- tariff scheme namely the renewable energy premium tariff in local isolated areas in developing countries could be an important stimulus for the development of renewable technology. Our main contribution beyond this theoretical assumption is the impact analyses of this alternative mechanism on social welfare. When we consider social welfare measured by both the sum of consumers and producer surpluses, one can remark from figure 8 that they are higher under the renewable energy premium and average tariffs, respectively. When the marginal cost tariff is applied, the producer loss is much higher compared to the benefits to the consumer, hampering an achievement of a significant social welfare benefit.

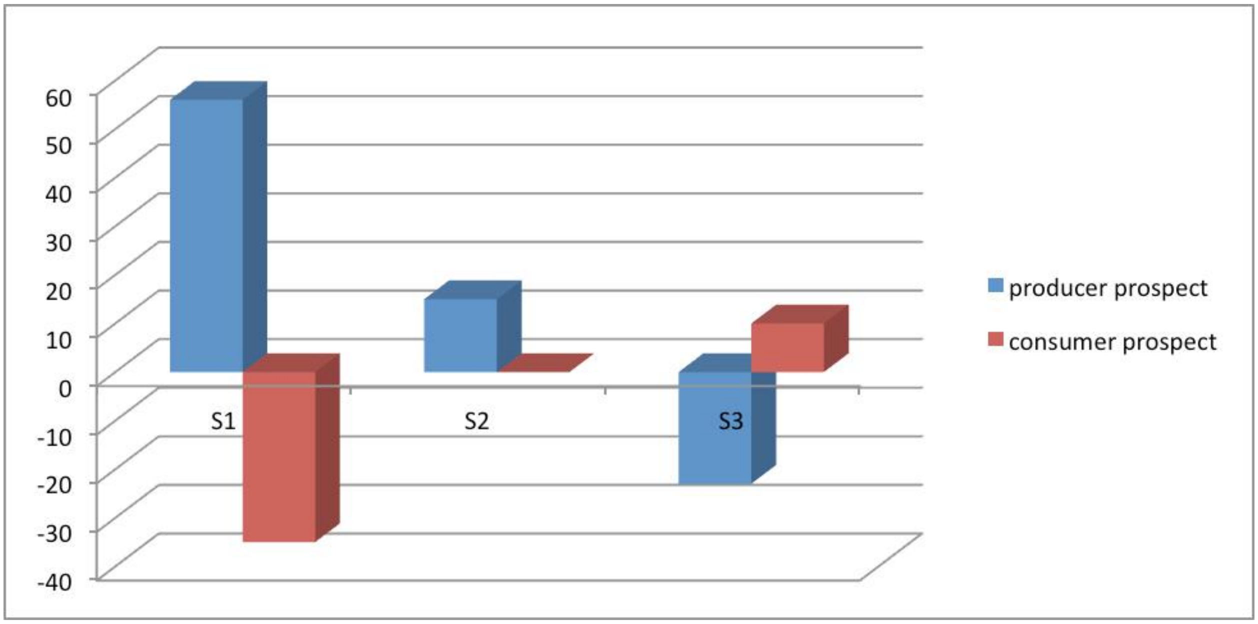

Figure 8: The structure of consumer and producer surplus

Furthermore figure 9 represents the structure of investment values under the price evolution. We represent investment values of both photovoltaic and wind technologies. One can see that before the break-event-point in (A) with a corresponding $\bar{p}$, investors will prefer to invest in wind compared to photovoltaic technologies because the evolution of energy price generates higher payoffs for wind compared to solar photovoltaic technologies. After the break-event-point, investors will prefer to invest in solar photovoltaic when the energy prices rise, because compared to wind investment, values of PV technologies become higher. Finally one can see also that at the break-event-point, the investment in PV technology presents the same decision value as the investment in decentralized wind technology option. $V_{PV}(p)$ and $V_w(p)$ represent investment values of photovoltaic and wind technologies, respectively.

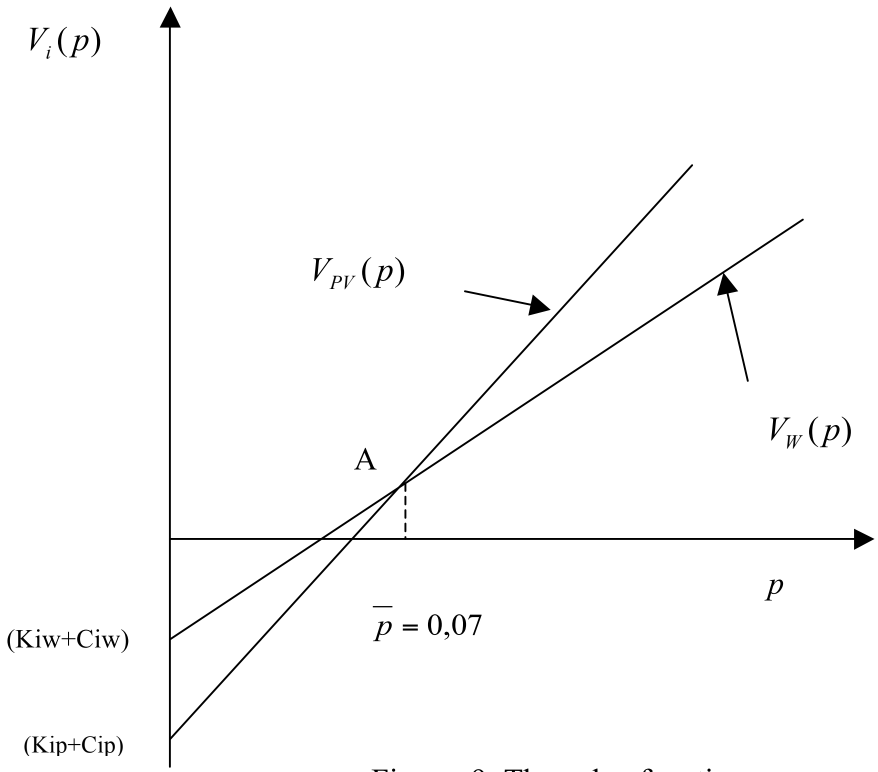

Figure 9: The value function

However, at least two important points must be taken into account when designing optimal energy tariff instruments in order to promote deployment of renewable technology in developing nations. First, energy policies must take into account the dynamic of technological bases within such nations. Second they should also integrate analyses of social welfare. The dynamic of technological bases highlights that an optimal design of the renewable energy premium tariff must include evolutions of the slope of marginal curve of renewable technologies. Theoretically, the computation of the slope of marginal curve requires a strong technological basis or knowledge basis - based on experiences- that enables the implementation of a learning process trajectory database. Moreover, market of renewable technology in Senegal is better characterized by technology purchase options than technology collaborations - at least in the innovation component - which make, in our case, a consideration of marginal curve's slopes inadequate. We assume that impacts of the slope of marginal curve on the design of renewable energy premium tariff is negligible because the support price retained is a price under which no investment could be carried out. The optimal price support for developing countries is that at which the technological basis – measured through a dynamic of marginal curve - is included in price support elaboration. The following figure shows evolution of renewable premium tariffs under renewable technologies capacities (figure 10). One can see that prices decrease with an increase of renewable technology. The figure 10 shows also evolutions of renewable energy premium tariff between wind and solar photovoltaic technologies. One can see that photovoltaic technology requires more support compared to wind technology. Moreover we can also see that renewable energy premium tariff decreases with an increase of technological capacities, which can be justified by two points. The first point is the scale effect while costs decrease with an increase of production capacities. Moreover as the renewable energy premium tariff follows cost trends, an increase (decrease) of the production is encompassed by an increase (decrease) of the tariff schedule scheme, respectively. The second point is the learning effect. An increase of learning rates associated with an increase of capacities produced correspond, all thing being equal, to a decrease of technological costs, which leads to a downward of tariff incentive.

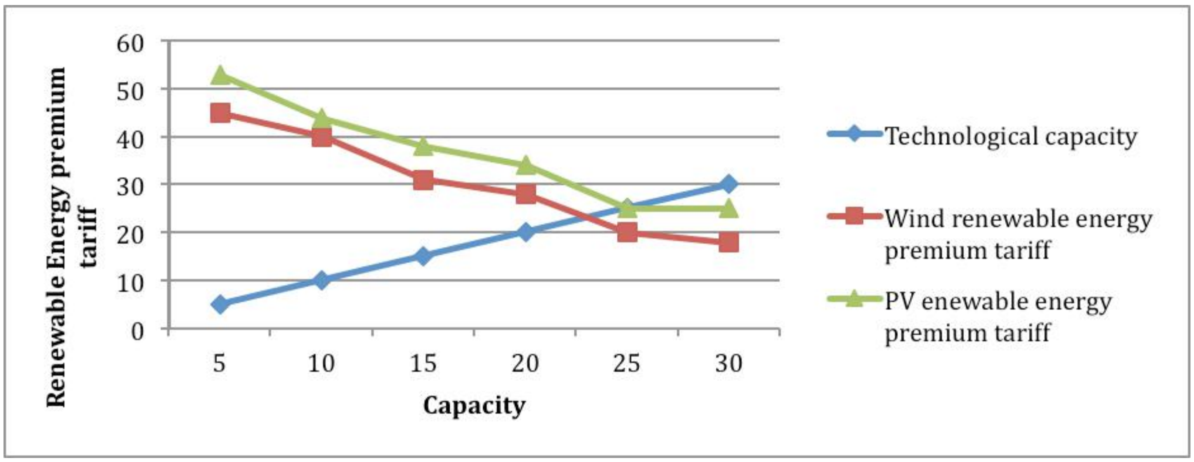

Figure 10: The renewable energy premium tariffs for selected technologies

The analysis of social welfare must also be carried out to minimize the welfare lost for population. The threshold price under which social welfare is damaged must be defined. Even if the purpose of price support is to increase renewable energy generation, its impact on local population must be computed to define optimal public allocations policies. If the price is directly supported by local population, as long as prices increase, social welfare is negatively damaged. Moreover, our finding indicates that a reliable support of renewable energy promotion should not be based on competition as the price mechanism under a competition structure does not generate an efficient result. Any investment performed within the competition tariff will generate an inefficient result.

The figure 11 shows the premium tariff over which the consumer surplus is deteriorated with the detriment of the renewable energy suppliers. This indicates beyond that point the producer will earn an abusive rent, because the social welfare becomes negative.

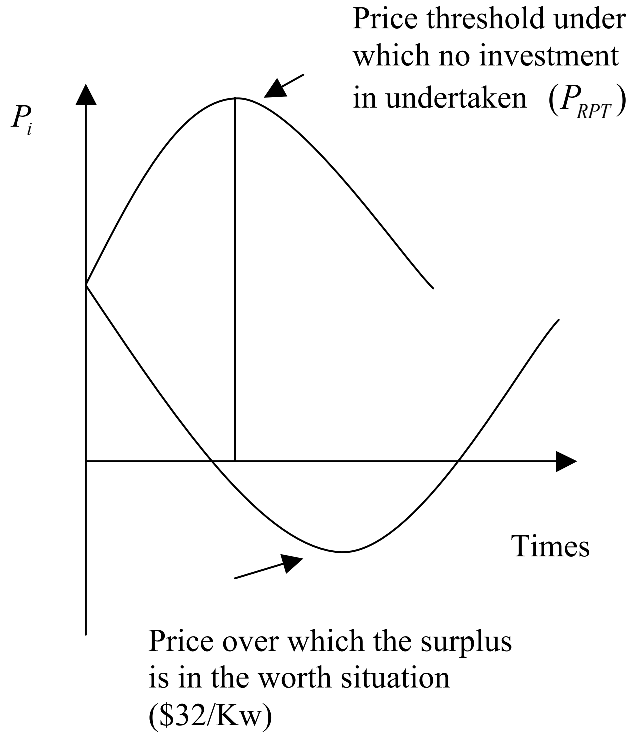

Figure 11: Price threshold function

Moreover, the impact on social welfare is not only caused by the tariff policy but also by any form of public policy. Some public policies such as subvention and the financing of research and development have a direct impact on both social welfare and the price level as they act directly on the long-term fixed capital cost. In this matter, a compromise must be found between increasing the capacity for renewable energy generation and minimizing its impact on social welfare.

4.6.a : Policy implications

Our results show efficiency and distributional effects of an array of an energy tariff incentive in order to promote the deployment of renewable technology through a market-oriented schedule. We find that such incentives strengthen investment in renewable technology because it increases payoffs from investor prospects. In terms of energy policies our results have two implications. The first implication (1) is related to the ability of incentive mechanisms to overcome existing barriers preventing deployment of renewable technologies in Senegal. The theoretical literature identifies cost, market and institutional factors as main barriers preventing deployment of renewable technologies in developing nations. Our findings indicate that price support could partially allow an overcoming of these barriers in the selected country. In fact, fixing prices higher than marginal costs allows potential producers to enter into the market by investing in renewable technologies. That means guarantees are provided by public authorities in order to ensure cost-competitiveness of renewable technology. Such guarantees encourage producers of renewable electricity to undertake investment because they expect a risk minimization during their investment period. The corresponding risks can take financial as well as non financial forms when investing in renewable energy in developing nations. The financial risk forms refer to the usual risk premiums for project finance loans (Dinica, 2006) while non financial risk could be divided between political and institutional risks. Political risks are those raised by political instability and violence within communities during an investment schedule. Whereas institutional risks refer to a lack of institutional reliabilities, which could skew decisions making and co-ordination of different actors involved during a planning horizon. Awerbuck (2003) proposed to include financial risks associated with the costs of electricity projects when comparing renewable with fossil fuel technologies. He argued that including such financial risk analyses could strengthen diffusion of renewable technology because although these technologies are capital intensive they pose lower risks on costs compared to fossil fuels. Although in our empirical investigation we did not introduce risk analyses, one can see from our results, that introducing renewable energy premium tariff strengthens investment decision while producers yield higher payoffs compared to other tariff schemes. Moreover fixing incentive mechanisms allows also an overcoming of some market barriers preventing deployment of renewable technology in developing nations. The market barriers lock-out renewable technologies through consumer choice of electricity from fuel resources. Compared to renewables, fuel technologies are more mature. Fixing a renewable premium tariff in developing nations could strengthen diffusion paths of renewable technologies by an increase of the share of renewable energy into the energy portfolio. This new framework gives more possibilities to consumers during their choice schedule. The second implication (2) of our result is related to impact analyses of price incentive on social welfare. Setting tariff incentive requires to keep in mind its impact on social welfare. Our results have shown that an array of renewable energy premium tariff provides a positive social welfare as long as the price incentive remain lower than 32 $/kw as evidenced by graphic 11. Once the price becomes higher than such a value, promoting renewable technology in Senegal through an increase of the renewable premium tariff generates negative social welfare. That means, although deployment of renewable energy should be the target, price support should be strategically that institutional reliabilities are met. Institutional reliability allows an encouragement of private involvement in renewable energy market as well as an increase of co-ordination efforts among actor networks.

4.6.b : Importance of institutional reliabilities

In developing nations like Senegal, policy incentives promoting deployment of renewable technologies should be carried out under reliable institutions. On the one hand, institutional reliability guarantees confidence between private actors and public authorities. Private sectors involved in renewable energy market in Senegal are largely focused on technology sale. Since the supply of renewable technology is mainly carried out either by NGOs or national electrification programs, the structure of the renewable energy market doesn't encourage involvement of private actors. The market transformation of renewable energy requires at the same time an array of incentive mechanisms (i.e renewable energy premium tariff) as well as a deep involvement of private actors in the energy generation cohort. Such involvement allows an integration of dynamics of private actors and their skills and knowledge. Private actors can have internal as well as external forms in Senegal. Internal forms are focused on local private actors like national small companies or private initiatives within the country whereas external private actors can be considered as foreign private investors. In each one of these forms, entrepreneurs need reliable institutions to undertake required investment in developing nations.

Furthermore, institutional reliability facilitates co-ordinations actions among involved actors in renewable energy market in Senegal. Different actors are present in renewable energy markets in Senegal. These actors, as mentioned above, are NGOS (i.e Environmental Development Action in the Third World: ENDA-TM), research centers (i.e Center for Renewable Energy based in Polytechnic School, Dakar), Senegalese Agency of Rural Electrification (ASER), Regulatory Committee of Electric Sector (CRSE). All these actors provide advice, research basis information for deployment of renewable technologies in the country. Encouraging reliable institutions could strengthen co-ordination actions from all these actors during renewable policy design.

Section 4.7 : Conclusion

The objective of this paper has been to investigate an array of renewable energy promotion tariffs on the promotion of renewable technology through decentralized processes in Senegal.

We developed a simulation model based on a linear programming approach in order to investigate the decision to invest in renewable energy sectors. Three different tariffing mechanisms have been selected: marginal, average and renewable energy premium tariff schemes. Our findings indicate that tariff policies could encourage promotion of renewable energy, although policy-makers must keep in mind impacts of such tariffs on social welfare. For example in our numerical investigations, a set of a renewable energy premium tariffs stimulates investment in renewable energy in decentralized supply in Senegal. Moreover we argued also that this incentive mechanism must be provided under reliable institutional structures. Such reliable institutional structures strengthen actor co-ordination and guarantees confidence between private actors and public entities during investment planning in renewable energy.

However, as mentioned above, beyond the decentralized approach, the transition towards renewable technology promotion in developing nation should integrate the centralized option as well. In fact considering the centralized option of renewable deployment within the electricity sector in developing nations facilitate the reinforcement of the socio-technological capacity of the electricity industry. Under this framework, the objective of the next chapter is focused on the electric sector. We use a bottom up model to analyse resort of renewable technology on the energy transition. Investigating renewable transitions within electric sector allows anticipating decisions of future investment in electric production park. Moreover t allows also inquiring if clean technologies are competitive once integrating into the national grid network in developing nations. This chapter is applied to South Africa and Senegal. Since renewable technologies are seen as important alternatives to diversify their electricity supply structures.

Appendix A

$$c^{'}(q) = \frac{p_0 q_0}{\mu}\left[-\mu\left(\frac{q_0}{q}\right)^{\mu-1} - \frac{q_0}{q^2}\right] = p \Rightarrow p_0\left(\frac{q_0}{q}\right)^{\mu+1} \quad \text{with} \quad \mu+1 = -\frac{1}{\sigma}$$

$$\Leftrightarrow \left(\frac{q}{q_0}\right)^{\frac{1}{\sigma}} = \frac{p}{p_0} \qquad \text{or} \qquad q = q_0\left(\frac{p}{p_0}\right)^{\sigma}, \sigma \prec 0$$

$$c(q) = c_0 + \int_{q_0}^{q} p_0\left(\frac{q_0}{x}\right)^{\mu+1} dx = c_0 + p_0 q_0^{\mu+1}\left[\frac{x^{-\mu}}{-\mu}\right]_{q_0}^{q} = c_0 + p_0 q_0^{\mu+1}\left[\frac{q^{-\mu}}{-\mu} - \frac{q_0^{-\mu}}{-\mu}\right]$$

$$\Leftrightarrow c(q) = c_0 + \frac{p_0 q_0}{\mu}\left[1 - \left(\frac{q_0}{q}\right)^{\sigma}\right]$$

Chapter 5: Modeling the transition towards a sustainable energy production in developing nations[35]

Abstract

The paper investigates how renewable technologies could promote the transition towards a sustainable energy production in developing nations. Based on two different developing nations in terms of economic, technological and institutional structure: South Africa and Senegal, we implemented scenarios in a bottom-up PowerPlan model in order to analyze the transition toward a sustainable electric production. Two scenarios have been considered: a business-as-usual (BAU) and a hybrid renewable energy (HRE) scenario. In the first scenario (BAU) we assume that the electricity demand is entirely satisfied by an increase of the investment in the current supply structure based on fossil-fuel energy source. Whereas in the renewable energy scenario, we assume 20% and 30% of the electricity supply being generated from renewable resources by 2020 and 2030 respectively. Focusing on wind and solar photovoltaic technologies, our results show the cost-competitiveness of renewable energy deployment in South Africa. In the case of Senegal, our results show that fossil-fuel resource remains the most competitive to generate electricity in the nation during the next coming years as long as environmental advantages of renewable resource are not considered. Our research indicates that in the case of a centralized electricity supply option, both a scale effect and a learning improvement could eventually strengthen the competitiveness of renewable technology deployment in developing nations.

JEL classification: Q42, Q47, Q49

Keywords: energy transition, renewable technologies, PowerPlan, South Africa, Senegal

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[35] This chapter is a slightly adapted version of Djiby-Racine Thiam, René M.J. Benders; Henri C. Moll, 2011. " Modeling the transition towards a sustainable energy production in developing nations", Forthcoming in Applied Energy

5.1 : Introduction

The promotion of renewable technologies has received widespread interest in developing nations. The reasons behind this increasing interest in clean[36] technologies can be at least summarized in two points. On the one hand, the promotion of renewable technologies in developing nations encourages the diversification of electricity supplies as well as a reduction of the share in the budget spent throughout the importation of fossil-fuel resources. On the other hand, the transition toward renewable technologies improves the environmental quality through a reduction of greenhouse gas (GHG) emissions during the electricity generation phase (World Bank 2006; IEA, 2002; Thiam, 2010a; Bhattacharyya, 2010). GHG emissions have important impacts on the climate, therefore, their increases are considered as a threat in modern societies. The threat of climate change in terms of economic, ecological and social impacts urges many developing nations to find alternative paths to providing electricity.

In this context, the objective of the paper is to analyze the impacts of renewable technologies to providing energy transition into the electricity sector in simultaneously South Africa and Senegal. These impacts are captured in terms of costs, electricity supply mix opportunities and environmental reduction advantages. These countries are chosen as benchmarks because they are active - although at different scales - in investigating potential contributions of renewable technologies into their electricity supply portfolio. Their objectives, to diversifying the energy supply system through the introduction of renewable technologies have a substantial weight on the agenda of their respective governments (DME 2002b; SIE 2007). For example South Africa has already set up, since 2009, financial mechanisms (feed-in-tariff) in order to increase the share of clean technologies into their energy balance. The Department of Energy of the Senegalese government has recently undertaken, since June 2010, an institutional re-arrangement and provided financial incentives in order to support the transition towards clean energy path. For example a Department of Renewable Energy has been newly created - within the whole Department of Energy - focusing entirely on the investigation of the determinants and schedules promoting a transition towards renewable technology structures within the nation. Some tax policies have been applied, during the importation of renewable technologies, in order to facilitate large deployments of these technologies in the nation. Furthermore, on the other hand, our approach is motivated by the fact that the transition towards a more sustainable energy structure into the electricity sector has been recently raises through different African nations (Brew-Hammond, 2010; Chineke et al, 2010). For example such transitions have been focused on electricity (Eggertson, 2002, Van der Plas et al, 1998), energy (Osei, 1996) and environmental[37] (Greg Hiemstra – van der Horst and Alice, 2009) sectors.

To simulate the role of renewable technologies into the energy transition in the electricity sector we use the PowerPlan simulation model. PowerPlan is a bottom-up simulation model and allows to answering questions like "what if ". In fact, through PowerPlan, from different scenarios, we assess economic and environmental impacts of the introduction of renewable technologies into the electricity system. Our model is calibrated from 2006 to 2030, therefore the final year of analysis is 2030 while two intermediate years are also analyzed, 2010 and 2020. The choice of the PowerPlan model is guided by two important points. On the one hand, PowerPlan has been successfully applied in both developed (Bender, 1996) as well as developing nations (Urban, 2009). Moreover, on the other hand, this model has the ability to overcome the structural limitation maintained in the field of energy modeling by introducing specificities of developing nations into the modeling process. While developed nations experienced a full access to electricity services in many developing nations, remote locations still lack access to electricity services. This situation could probably hampered the economic development in these areas since electricity access is considered as an important driver of economic development (Thiam, 2009, Bhattacharyya, 2006).

The paper is organized as follows. The section 2 describes the structure of the power sector in both South Africa and Senegal. The section 3 presents the structure of the PowerPlan, a bottom-up model used to simulate the contribution of renewable energy to promoting energy transition into the electricity sector. Section 4 presents scenarios developed to calibrate the model. In section 5 we present the finding results. Concluding remarks are provided in section 6.

Section 5.2 : The Power sector in South Africa and Senegal

The structures of the power sector between South Africa and Senegal are largely different. While in South Africa more than 70% of the electricity supply is derived from coal-based resource, in

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[37] Environmental impacts of transitions are mainly based on impacts of the use of clean technologies on both the deforestation and desertification in developing nations.

Senegal the combination of oil and gas represents more than 80% of the electricity supply structure (DME, 2003; SIE 2007). Moreover the power industry in South Africa is by far more structured than the Senegalese power sector.

5.2.a : South Africa

The power sector in South Africa is characterized by an important share of coal resources, which are the main input during the electricity production phase. South Africa has at its disposal an important reserve of coal resources, which are estimated to represent more than 55 billion ton and are used to generate the bulk of grid electricity. Nuclear power represents around 5 % of the total generation capacity. The electricity service is mainly provided by ESKOM - a national power utility - which owns and operates around 92% of the electricity generation capacity. The rest of the electricity supply is provided by municipalities and private sectors (figure1). It is also important to acknowledge that South Africa imports oil mainly from Saudi Arabia, Iran, Nigeria and Angola and there are some independent power producers (IPPs) into the supply structure. The electricity transmission is carried out by ESKOM throughout the national network based mainly in urban areas letting remote rural populations in a position where electricity access is compromise. Moreover through the Southern African Power Pool[38] (SAPP), the country export electricity in some neighboring countries.

The national electricity access rate in South Africa is the highest in Sub-Saharan Africa. From table 1 one can see that coal resource is widely used to generate electricity. The contribution of renewable resource is mainly dominated by hydro service that represents in average around 6% of the electricity supply source. Beyond hydroelectricity one can observe that wind energy contributed by 3.2 MW among the renewable architecture platform.

Table 1 : Eskom Power Station in 2008

Baseload	Capacity (MW)	Other	Capacity (MW)
Coal-fired		***Hydro***	
Arnot	2.100	Gariep	360
Duvha	3.600	Vanderkloof	240
Hendrina	2.000	***Hydro distribution***	
Kendal	4.116	First Falls	6.4
Kriel	3.000	Second Falls	11.0
Lethabo	3.708	Colley Wobbles	42.0
Majuba	4.110	Ncora	24.0
Matimba	3.990	***Pumped storage***	
Matla	3.600	Drakensberg	1.000
Tutuka	3.654	Palmiet	400

[38] The SAPP was established in 1995. It currently has 12 members (South Africa , Botswana, Swaziland,

New Build (coal)		Ingula (new build)	1.332
Medupi	4.788	***Open cycle gas turbine***	
Return to service (coal)		Acacia	171
Camden	1.600	Port Rex	171
Grootvlei	1.200	Ankerlig	592
Komati	1.000	Gourikwa	444
Nuclear		Gas I (new build)	1.036
Koeberg	1.930	***Wind***	
		Klipheuwel	3.2
Total baseload	44.396	**Total other**	5.833
Coal share of total capacity	42.466	**Total overall capacity**	50.229

Source : US DOE (2008)

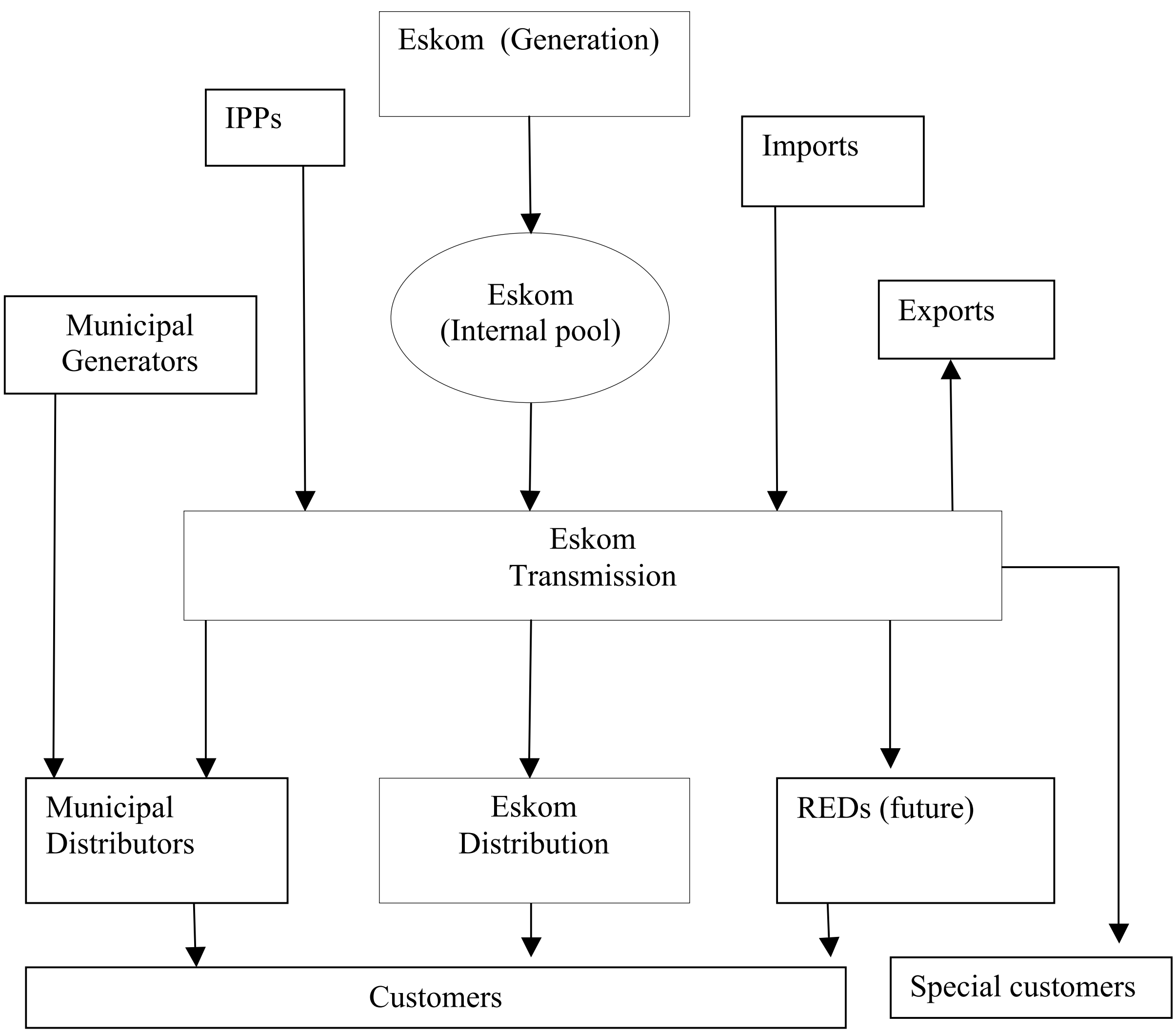

Figure 1 : structure of the power sector in South Africa

5.2.b : Senegal

The electricity sector in Senegal is characterized by a dependency on fossil fuel (principally oil and gas), which provides more than 80% of the current electric capacity. For example the main part of the electricity supply is generated from Diesel, which represents more than 60% of the supply. Beyond, Diesel and steam coal is used in order to promote electricity within the nation. Moreover, since 2002 the country provides hydroelectricity generated from the Manantali dam. The Manantali dam is a hydroelectric dam of the Bafing River in Mali. The electricity generated from the dam is shared between Senegal, Mali and Mauritania. The Manantali dam possesses a capacity of 200 MW within which 35% is intended for consumption in Senegal. The electricity service is provided by SENELEC - a national power utility - which owns and operates around 60% of the electricity generation capacity. The rest of the amount of the electricity supply is provided by private components (figure2). The country imports a large share of fossil fuel resources particularly oil. The electricity transmission is carried out by SENELEC throughout the national network based mainly in urban areas. The table 2 shows the existing power capacity of the country.

Table 2 : SENELEC power stations in 2010

Baseload	Capacity (MW)	Other	Capacity (MW)
Bel Air		Secondary Plants	21,9
CI	9	Coal	60
CII	51,2	Hydro	70
CVI	60		
TAG IV	32		
Cap de Biches			
CIII	87,5		
CIIITAG	60,5		
CIV	86		
CV	9,3		
Regions			
Saint-Louis	6		
Kahone	14		
Tamba	7,7		
Ziguinchor	14,2		
Total baseload	437,4		151,9
		Total overall capacity	589,3

Source : combined by the author based on the Geographic Information System (GIS, 2007),

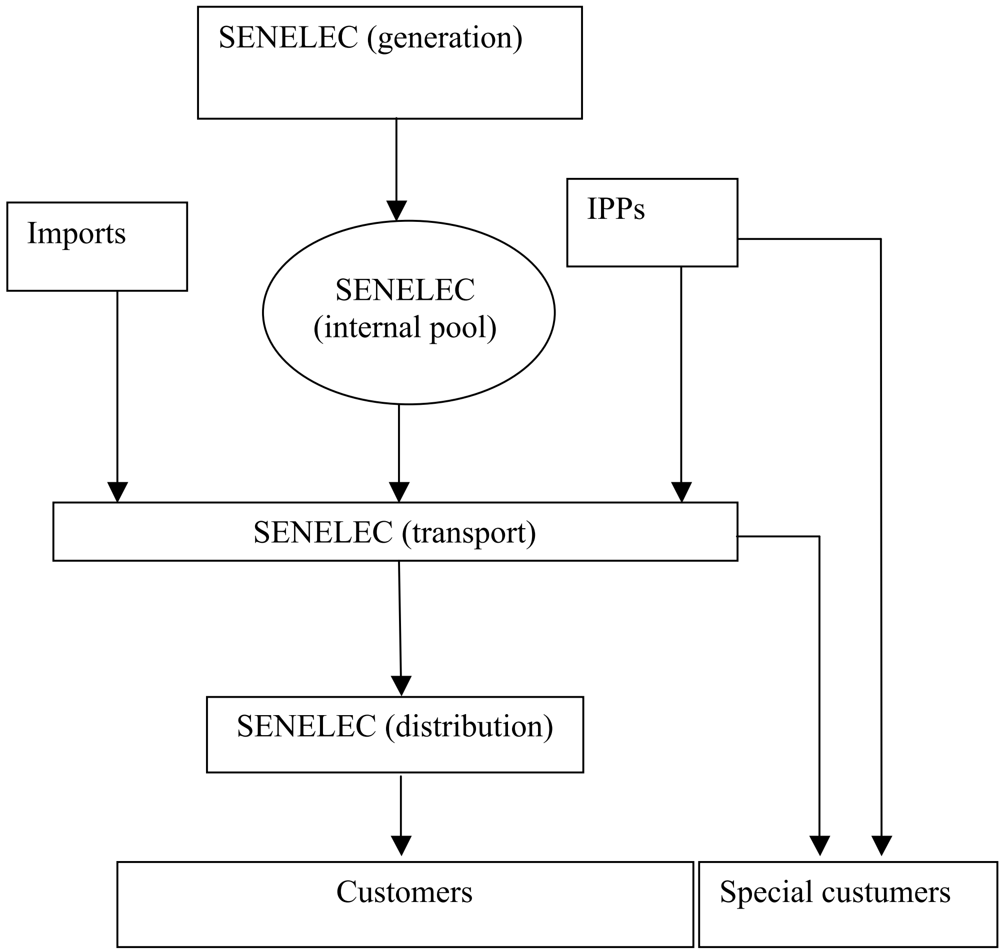

Figure 2: structure of the power sector in Senegal

Section 5.3 : Model Overview

An end-oriented simulation model - PowerPlan - has been used to analyze impacts of an increase of renewable technology in the electricity system in both South Africa and Senegal. Under PowerPlan, such impacts can have economic, environmental and physical orientations (Benders, 1996, Urban, 2009). The economic impacts of the transition towards renewable technologies within the electric sector are mainly focused on the costs assessment during the electricity generation phase, while environmental and physical impacts are focused on the level of the emission reductions and the amount of electricity generated and capacity installed, respectively. Moreover the model provides an objective reading of a scenario-making in terms of electricity generating park and allows answering the type of questions like “what if”. The type of question “ what if” could be interpreted as how decision variables will behave if changes on inputs variables

The analysis of a transition towards a sustainable energy production in developing countries is well performed in the literature (George and Banerjee 2011; DeFries and Pandey 2010, Pachauri and Jiang, 2008; Marcotullio et al 2007; Urban et al, 2007; IPCC 2000a; Bouwman, Hartman and Klein Goldewijk, 2006). Indeed since both the objective to promote a diversification of electricity supplies and to reduce environmental emissions were worldwide recognized, several quantitative tools were developed in order to model impacts of a transition to a more sustainable energy production system. Two forms of energy models exist in the literature: a top-down and a bottom-up modeling approaches. A top-down approach is mainly used by economists and is a partial equilibrium model through which the user simulates impacts of energy and economic policies on both energy and non energy markets (employment market, service market, etc) . Through top-down models, the user can analyse sectoral and/or market impacts of strategic policies like stimulating R&D and increasing energy tariff. Typical examples of top-down models are, for example, Computable General Equilibrium (CGE) and Input-Output (IO) models. Contrary to the top-down models, the bottom-up approach presents specificities of technologies and remains mainly based on an energy supply-side modeling approach. The bottom-up model determines the best way to expand the electricity generation capacity through either an optimization or by analyzing scenarios. The bottom-up model determines the optimal strategy of energy policy through either a minimization of the total discounted costs or by directly setting up scenario analysis. Furthermore through bottom-up approaches the user can chose between dynamic optimization and simulation tools in order to determine optimal capacity expansion. Finally there have been also investigations attempting to couple top-down with bottom-up models through hybrid approaches (Ian Sue Wing 2006; Frei et al 2003). The hybrid approaches combine technologies specificities of bottom-up and sectoral analysis of top-down approaches.

In the cases of South Africa and Senegal, quantitative assessments of impacts of sustainable energy transition have provided interesting results. Winkler (2006) has found that a transition towards sustainable energy production within the electricity sector in South Africa could increase energy access by 92% in 2025 compared to 2001 levels. Beyond an increase of energy access such transition reduces greenhouse gas (GHG) emissions generated during the electricity production. For example, GHG emissions in 2025 are assessed at 32 Mt CO2, 5% lower than in the base case (Winkler, 2006). Furthermore, even if this transition requires R. 6 billion this represents only 0,03% of the required investment in the baseline case. This finding indicates that a transition towards sustainable energy in South Africa within the electricity sector is cost-competitive. Howell et al (2005) analyze a transition towards sustainable energy production in a more schedule by consumers. They investigate a transition, in rural areas in South Africa, from classical end-users to environmental-friendly schemes. They consider a base case, a stand-alone, a grid electrification, a electrification with cost reflective electricity prices and a externalities scenario. The base case scenario assumes that no electrification program will take place while the stand-alone and grid electrification scenarios assume a decentralized electricity supply option and a national electric network extension respectively. Finally in the electrification with cost reflective electricity prices and externalities scenarios they assume an electricity demand management with flexibility on prices and internalization of the negative environmental costs from fossil-fuel technologies respectively. They found that, under the base case and stand-alone generation scenarios, wood resources still continue to dominate the final energy supply architecture. For the grid extension scenario they found paradoxically that consumers prefer investing in distributed generation and connection instead using alternative paths from renewable resources to getting energy. They conclude that as long as the electricity consumption volumes remain low, grid connection could provide a profitable alternative. Although poor households have access to electricity, they continue to use wood for a satisfaction of basic needs such as cooking and heating. Under the electrification with the cost reflexive scenario, consumers switch their consumption between peak and off-peak times. To minimize their electricity expenditures they manage their demand in a more cost-competitive schedule. Finally, in the last scenario the model the LPG() as incorporating environmental externalities in the electricity tariff schedule increases the electricity price. Winkler et al (2009) analyze transitions towards clean energy by simulating an increase of 27% and 50% of renewable energy in 2050. Using a bottom-up MARKAL optimization model they have shown that the mitigation costs decline considerably in both two scenarios once the learning process of the renewable technologies is integrated (Winkler et al 2009). Their results show that technology learning flips the costs, saving R143 when a higher penetration rate is assumed, the incremental costs added beyond the base case decline from R92 per ton to R3.

In the case of Senegal, quantitative analyses of the transition towards renewable technologies remain few compared to South Africa. Lazarus (1993) analyzed this kind of transition through a project carried out simultaneously by the Environment and Development in the Third World (ENDA-TM) in Dakar (Senegal) and the Stockholm Environment Institute (SEI). This project aimed to build institutional capacity for integrated energy-environment planning in Africa.

From an economic prospect the transition from fossil-fuel to renewable resources (hydro) leads to a fall of oil consumption by 31% (Lazarus, 1993). From the environmental viewpoint the

relative to the reference case, leading to only a 14% increase in total CO_2 emissions over the 17 years study period.
On the basis of these experiences the contribution of this paper is twofold. On the one hand, it presents an updated assessment of the transition towards sustainable electricity production in both South Africa and Senegal. On the other hand, the paper integrates the objectives of the two different governments to increase the share of renewable technologies in the energy balance.

5.3.a : Structure of PowerPlan

PowerPlan is a bottom-up model with the objective to simulate the transition towards a new energy production path. In doing so, the model simulates the electric power generation during the planning horizon. The planning horizon could take one year (as in this paper) or more years, depending on the availability of data and the investigation targeted by the user. Once the complete one year calculation round is retained the annual demand for electricity is calculated from the Load Duration Curve (LDC) and the Simultaneous Maximum demand (SMD). The LDC illustrates the relationship between generating capacity requirements and capacity utilization. This curve represents the timely variation of the electricity demand from base load to peak load. The SMD represents the peak demand during the time of the electricity consumption. This characterization is important as electricity consumption varies throughout seasons, hours within a day and levels of production activities. For example, the energy demand is higher during winter compared to summer or during day rather than night. The energy planning model should incorporate such variations to provide optimal strategies during electricity production. Furthermore in PowerPlan, the means of production are the electricity generating equipment installed. Using the merit-order approach, annual fuel inputs are calculated from the electricity generated per plant. In combination with exogenous fuel-price times-series, investment costs and interest rate, KWhe-generating costs are calculated. The emissions are calculated from the fuel use, fuel and power plant characteristics. The following figure 3 shows the structure of the PowerPlan model.

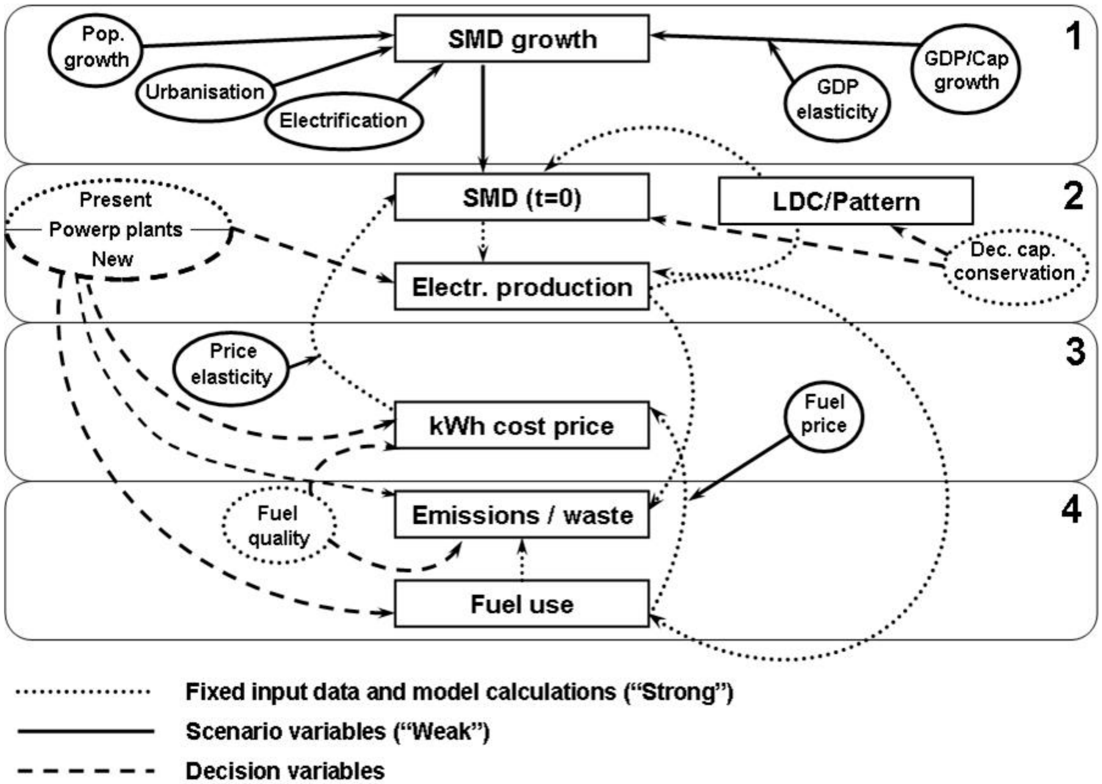

Figure 3 : shematic overview of the PowerPlan model

Furthermore in PowerPlan three different types of data are needed: the "strong" and "weak" input data and the "decision variables" (Benders, 1996). The "strong" input data are data showing the economical (capital, operating and maintenance costs), environmental (CO2, SO2 and Nox emissions) and technical (efficiency, capacity, fuel type, first and last year of operation etc.) characteristics of selected technologies. These parameters are given by the characteristics of the technology and cannot be changed. The "weak" input data are those which can be changed in order to set up scenarios. Under these values the user could make assumptions on expected future developments. This includes macro-economic variables such as GDP per capita and oil price or technico-economic variables such as the introduction of new technologies with different technical characteristics. Finally, the "decision variables" represent the input data during the simulation i.e. the type of power plants and decentralized capacity that should be installed, conservation measures that should be taken and the type of pollution abatement measures that should be undertaken.

Building a PowerPlan model requires to combining four modules namely a macro-economic forecasting module, the production simulation module, a costs module and the fuel and environmental module (Benders, 1996).

1. a macro-economic forecasting module from which the growth in electricity demand is determined by :
   - The growth rate of the electricity demand which is assumed to be linear with the growth rate of the population.
   - The economic growth rate (GDP per capita) coupled by an elasticity (GDP elasticity).
2. The production simulation module in which the electricity production is calculated from the LDC and the SMD, and in which the supply reliability of the generating system is calculated. The LDC and SMD can be influenced by the installation of decentralized capacity and by conservation measures
3. A cost module in which the KWhe cost-price is calculated using fixed and variables costs data. The fixed costs are focused on the initial capital investment cost and the general system characteristics while the operating and maintenance costs are mainly fuel costs and daily maintenance costs. The change in the KWhe cost-price influences the SMD for the next planning horizon.
4. The fuel and environmental module in which the fuel use and associated emissions as well as other solid waste products are calculated, depending on the electricity generating system characteristics and fuel quality.

Section 5.4 : Scenario building

The objective of this section is to provide scenarios on which implementing a transition towards renewable technologies in South Africa and Senegal could be based. Scenario analyses play an important role in energy planning (OECD/IEA, 2003). They provide possible evolution paths on which energy policy-makers could anchor their previsions. Using scenario analysis in the energy sector strengthens the investigation of the economic and environmental impacts of the global warming (IPCC, 2001), or a diversification of energy supply (OECD/IAE, 2003). To build suitable scenarios for a transition towards a sustainable electricity generation in South Africa and Senegal, we follow four main steps. In the first step we identified our objective, which is the assessment of the economic and environmental impacts of a transition towards sustainable electricity production. After having identified this objective we determined, in the second step, decision factors which represent the variables allowing to take decisions. These decision factors could be seen as indicators facilitating to take decisions. Through this paper we identified the costs scenarios. In the third step, we identified the driving forces of these preceding decision factors. The driving forces can be seen as factors influencing positively or negatively decisions factors. We identified four driving forces of the decision factors: the energy demand, additional capacity installed, level of technological innovation, fuel prices on the international oil and gas markets. All these four driving forces have impacts on the evolution of the decision factors. Finally in the last step, we set up scenarios to simulate a transition towards sustainable electricity generating technologies. We differentiated between a business-as-usual (BAU) and a hybrid renewable energy (HRE) scenario. The BAU assumes no additional renewable technologies in the energy supply chain while under the HRE scenario a mix of energy supply through an introduction of renewable resources has been assumed. The figure 4 summarizes the four main steps forwarded to build the scenarios.

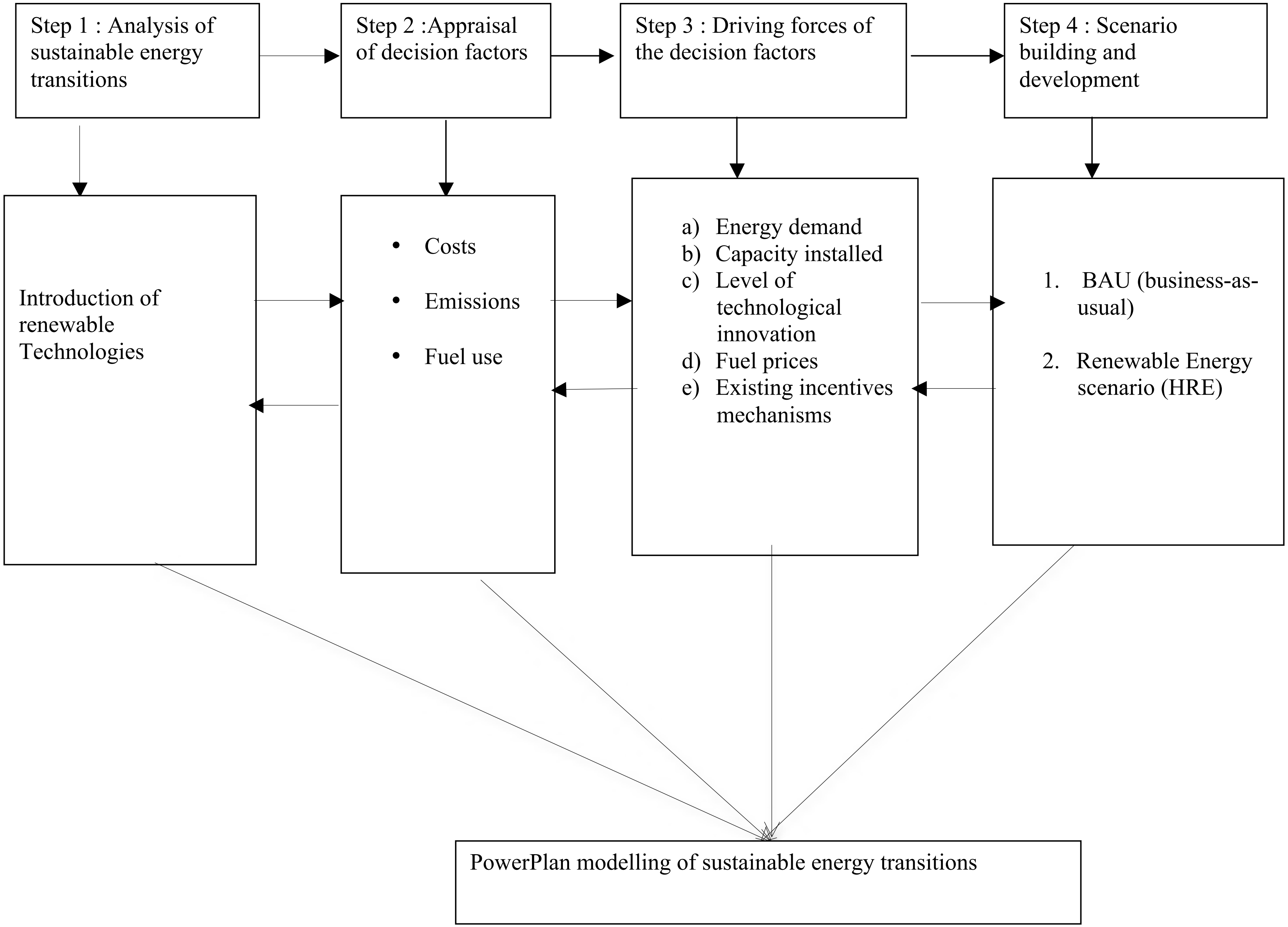

Figure 4 : Overview of the scenarios formulations

5.4 : Scenario analysis

As explained above, we analyzed two different scenarios: the business-as-usual (BAU) and the hybrid renewable energy scenario (HRE).

5.4.a :Business- as-usual

The BAU assumes no additional renewable technologies in the electricity supply chain. The electricity supply chain is composed by fossil-fuel and the existing renewable resources (hydro, wind, solar off-grid etc). The BAU represents the energy pathway that follows the continuation of the current investment trend using a forecast on existing energy demand. Through the BAU schedule, we differentiate between BAUlow, BAUmedium and BAUhigh scenarios. Under the BAUlow scenario, we assume that the electricity demand increases at lower growth rate while in BAUmedium and BAUhigh scenarios we assume a medium and a high rate of an increase of the electricity demand respectively. Under PowerPlan the energy demand is driven by both the GDP and the population, therefore, an increase (decrease) of the energy demand is caused by a simultaneous increase of the population and GDP (decrease of population and GDP) respectively. In our model, to represent the low, medium and high evolution of the electricity demand we referred to the evolution of the energy demand in both South Africa and Senegal during the last decades. Following the database of the International Energy Agency, the evolution of the electricity demand in South Africa could take the following values: low 2,5%, medium 5% and high 7%. In the case of Senegal, the evolution of the electricity demand could take the following forms: low 1,5%, medium 2,5% and high 5%. These evolutions are anchored on the average evolution of the electricity demand during the past three decades in the mentioned above countries.

5.4.b : Hybride renewable energy (HRE)

The HRE scenario assumes a diversification of the electricity supply chain. We assume that the amount of renewable resource in the supply-side will represent 15% in 2020 and 30% in 2030. The share of 15% of a renewable resource is chosen because it corresponds to the expected amount of clean energy targeted by the two respective governments. In fact, for both South Africa and Senegal, the governments have outlined a clear objective of increasing the share of renewable technologies in the electricity supply system. The Department of Minerals and Energy (DME) of the Republic of South Africa has specially published a white paper dealing with the promotion of renewable energy, targeting an increase of clean resources by 15% (Winkler, 2005). For Senegal, in the letter of the development of the energy sector (LDES, 2007), the government has outlined an objective to increase the share of renewable resources by 15% in 2020. The choice of the scenario of 15% of renewable resources in 2020 is retained in order to harmonize the calibration of the model and to provide an annual comparison between the two countries. With the share of 30% of renewable resources in 2030, we aim to change scale and to analyze a structural modification of the electricity supply structure in 2030. This can be expected once assuming a real willingness to change the electricity park through a mobilization of large investments and by setting up incentive mechanisms stimulating large adoption of renewable technologies. This scenario remains in our view realistic for two reasons: on the one hand, a high increase of fossil-fuel prices on international markets will open opportunities for developing nations to investigate alternative ways to providing electricity. On the other hand, to reduce the fossil-fuel bills, diversify and sustain the electricity supply, important investments in renewable technologies are required. Therefore our HRE scenario takes the following form: HREPV (15%) , HREW (15%) and HREPVW (30%). The hybrid renewable energy scenario of 15% assumes a schedule of introducing independently wind and solar PV in the electricity supply. Whereas the hybrid renewable energy of 30% assumes a simultaneous introduction of wind and solar PV in the supply chain. Contrary to BAU in which electricity demand has different trends (high, low and medium), in the HRE scenarios, such trend is assumed to only follow a medium trend. This assumption is made in order to facilitate comparisons between scenarios. The table 3 summarizes the scenarios developed in the paper.

Table 3: scenarios analysis

Scenarios	Electricity demand	Population growth	Economic growth
BAUlow	low	low	low
BAUmedium	medium	medium	medium
BAUhigh	high	high	high
RE 15% (PV)	medium	medium	medium
RE 15% (Wind)	medium	medium	medium
RE 30% (PV-wind)	medium	medium	medium

Section 5.5 : Results and discussions

5.5.a : Results of the BAU scenarios

The BAU scenarios are calibrated in 24 years from 2006 to 2030 in order to take into account current energy development plans of South Africa and Senegal. The three BAU scenarios (BAUlow, BAUmedium and BAUhigh) simulate what will be the outcome of the physical supply source for South Africa and Senegal if the current pathway is followed. In the BAU scenarios, no additional renewable technologies are considered in the supply system. The share of renewable energy available in the supply chain is provided through the existing renewable resources. The increasing energy demand is covered through an increase of the existing fossil-fuel technologies to follow the old investment trend of the countries.

The table 4 shows that the coal share among the total installed capacity in South Africa decreases from 2006 to 2010 and then increases from 2010 to 2020 under BAUhigh, BAUlow and BAUmedium. The fossil fuel resource from natural gas increases from 2006 to 2010 and then started to decreasing between 2020 and 2030. Coal accounts for more than 90% of the fossil fuel share whereas natural gas accounts for on average 1% under BAUhigh and BAUlow and 2% under BAUmedium in the context of South Africa. The table 1 shows that after having increase until 2010 the share of nuclear decreases under BAUhigh, BAUlow and BAUmedium. For hydroelectricity it's contribution increases under the BAU scenarios. One can remarked that for South Africa the share of renewable energy among the total installed capacity does not exceed 2%. Moreover, the variations of both hydro and gas turbine remains lower compared to the variation of the other energy resources. Therefore one can conclude that for South Africa, coal will remain the main source to providing electricity services (table 4 and 5). In 2010, 2020 and 2030 coal resources will cover more than 90 % of the resources used to produce electricity in the three scenarios (BAU low, BAU medium and BAU high).

Table 4 : Installed capacity, electricity generated, generation costs and SO2 and NOx emissions for the BAU scenarios for South Africa

	Capacity (MWe)				Electricity (Twhe)				Costs ($ US /kwhe)				SO2 and NOx (kton		
Scenario /years	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020
BAUhigh	40.053	44.455	53.527	60.527	240.633	291.709	358.024	406.983	0.0414	0.0438	0.0441	0.0456	1958	2250	2536
BAUlow	40.053	44.455	53.527	60.527	240.633	258.825	313.427	382.814	0.0414	0.0427	0.0426	0.0436	1958	2085	2285
BAUmedium	40.053	44.455	53.527	60.527	240.633	273.765	349.451	406.753	0.0414	0.0431	0.0434	0.0445	1957	2164	2494

Table 5 : Share of different types of energy among the total installed capacity for the BAU scenario for South Africa

Share	Coal				Nuclear				Hydro				Gas Turbine			
Scenario /year	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030
BAUhigh	96	90	92	94	3	3.98	3.5	1.5	0.8	0.02	1.5	1.5	0.2	0	3	3
BAUlow	96	95	96	96	2.7	3	2	1.08	0.8	0.8	1	1	0.5	1.2	1	1.92
BAUmedium	96	93	93	95	1.7	3.5	3.3	1.5	0.8	1	1.5	1.5	0.5	2.5	2.2	2

Table 6 : Share of different types of energy among the total installed capacity under RE scenarios for South Africa

	Combination PV-Wind				Coal				Nuclear				Hydro				Gas Turbine		
	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020
RE 15% (PV)	4	17	16	19	86	71	73	70	4	3.5	3	2	5	4	5.5	6.5	1	4.5	2.5
RE 15% (Wind)	4	17.3	16.2	19.2	86	71	73.2	69.8	4.3	3.4	3	1.75	4.8	3.8	5.5	6.5	0.9	4.5	2.1
RE 30% (PVwind)	0.13	18.8	26.8	31.1	89.5	69.7	64	59.7	4.5	3.3	2.5	1.5	5	3.7	4.7	5.5	0.87	4.5	2

Table 7: Share of different types of energy among the total installed capacity for the BAU scenario Senegal

	Hydro				Coal				CC				Steam				Diesel					
	06	10	20	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2[illegible]
BA Uh	12.7	7.7	6.2	6.7	-	21.1	17	18.4	10.6	6.4	5.1	5.6	8.5	7.5	4	4.3	57.6	48.3	52.7	50.8	10.6	[illegible]
BA Ul	12.7	7.7	6.1	6.7	-	21.1	16.9	18.4	10.6	6.4	5.1	5.6	8.5	7.5	4	4.3	57.6	48.3	52.7	50.9	10.6	[illegible]
BA Um	13.7	8.9	8.2	7.1	-	24.6	22.7	19.5	11.4	7.4	6.8	17.7	9.1	5.9	-	2.9	54.4	45.6	55.2	46.6	11.4	[illegible]

Table 8 : Installed capacity, electricity generated, generation costs and SO2 and NOx emissions for the BAU scenarios for Senegal

	Capacity (MWe)				Electricity (TWhe)				Costs				SO2 and NOx			
	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	203[illegible]
BAUhigh	472	781	972	894	2.409	2.982	4.824	6.068	0.0773	0.0652	0.0743	0.0826	15.93	20.97	33.21	38.[illegible]
BAUlow	472	781	972	894	2.409	2.589	3.031	3.522	0.0773	0.0637	0.0682	0.0747	15.93	17.96	20.67	24.[illegible]
BAUmedium	439	671	726	843	2.366	2.684	3.427	4.351	0.0778	0.0649	0.0699	0.0730	15.56	18.98	23.61	27.[illegible]

Table 9 : Share of different types of energy among the total installed capacity under RE scenarios for Senegal

	Hydro				Coal				CC				Steam				Diesel				GT				PV-wind			
	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030	2006	2010	2020	2030
RE15% PV	8.5	6	6.3	6.9	-	16.6	17.4	19	7	5	5.3	5.7	5.6	4	-	-	64.7	53	55	53.3	7	5.4	5.3	3.4	7.2	10	10.7	11.7
RE15% wind	7.4	5.2	5.5	6.3	-	14.4	15	17.5	6.1	4.3	4.5	5.3	4.9	3.5	-	-	69	54.8	56.6	51.7	6.2	4.3	4.5	3.2	6.4	13.5	13.9	16
RE30% PVwind	12	7	5.9	4.5	-	19.4	16.4	12.4	10	8.8	12.4	16.9	15.2	4.7	-	-	47.8	48.3	40.3	33.7	10	5.9	5.2	2.2	5	5.9	19.8	30.3

The table 4 shows the estimated effects of the business-as-usual approach on the installed capacity, electricity demand, generation costs and the environmental emissions for the future. The figure 5 shows how different power generating plants are combined under the business-as-usual scenario in South Africa. One can remark also that coal resources contribute considerably into the supply option in order to satisfy the demand.

For Senegal, the electricity supply chain will also be driven by fossil-fuel technologies (table 7 and table 8). In fact coal share decreases from 2010 to 2030 under the BAUmedium scenario. Under the BAUhigh and BAUlow scenarios, coal resources decreases from 2010 to 2020 and then started to increasing again from 2020 to 2030. Originally coal resources did not have an important weight in the structure of energy supply of Senegal. But the increasing electricity blackouts has motivated the government to investigate a diversification option of the supply chain through an introduction of a coal plant in 2010. The share of diesel in the supply structure remains the higher compared to other energy sources. For example in average 50% of the electricity is supplied by diesel generators. However although the share of hydroelectricity in the supply chain in Senegal (in terms of percentage) remains much higher than in South Africa (approximatively 10% vs approximatively 5%), the share of hydroelectricity decreases drastically from 2006 to 2030 under all the BAU scenarios. This can be explained by the availability of the Manantali dam which is shared between Senegal, Mali and Mauritania. The figure 6 shows how different power generating plants are combined under the business-as-usual scenario in Senegal

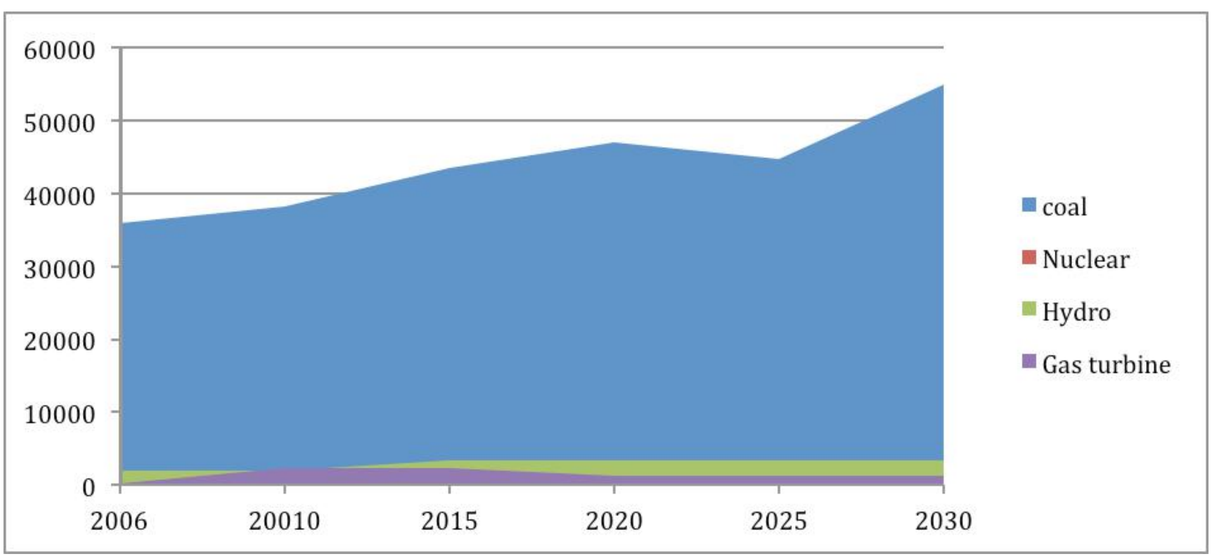

Figure 5: Installed capacity under BAU scenario in South Africa

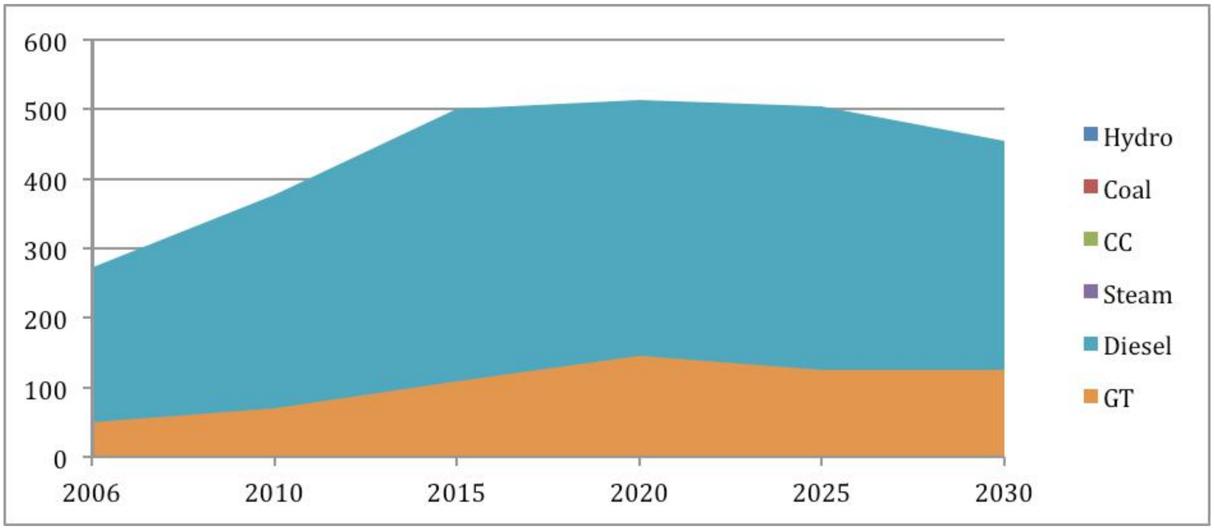

Figure 6: installed capacity under BAU scenario for Senegal

5.5.b: Results of Renewable energy scenario

The renewable energy scenario simulates what happens if South Africa and Senegal diversify their energy supply chain from fossil fuel to renewable resources. Of course such transitions could not be introduced in a radical scheme, but should mainly be carried out under an evolutionary path. Such transitions also require a set up of policies stimulating adoption of renewable technologies at the global scale. In both the selected countries, these policies exist although they take different forms. In South Africa, as explained above, since 2009 a feed-in-tariff scheme has been introduced in order to promote the diffusion of clean technology. For Senegal, since June 2010, the government has adopted a set of tax incentives in order to promote the deployment of renewable technologies in the supply chain. In the renewable energy scenarios, we assume that the share of renewable resource increases to 15% in 2020 and 30% in 2030. Furthermore, as said above, in the RE scenarios we assumed also that the electricity demand follows the medium increasing trend. Moreover in the renewable energy scenarios, we introduced the learning rate effects within technologies throughout a decrease of technological costs over times.

For South Africa it can be seen that 15% of the total capacity installed comes from PV and wind under RE15% scenario in 2020, while 30% of the total capacity installed is renewable installed in 2030. It can be seen from table 6, that the share of coal-based and nuclear resources decreases for all three scenarios. The share of hydro firstly decreases from 2006 to 2010 under the three renewable scenarios, while it started to increasing from 2010 to 2030 under RE15%PV, RE15%wind and RE30%PVwind respectively. The figure 7 shows the contribution of the different types of renewable energy under the renewable deployment scenario. Once can seen that from the figure 7 that coal resource still dominates the electricity supply structure in South Africa in 2030 under the three different renewable deployment scenarios. Furthermore we found that for South Africa in both HREPV (15%) and HREW (15%) scenarios the costs increase while they decrease in 2020 under the HREPVW (30%) once wind and PV are combined (table 6). This is justified by the introduction of additional PVs – which are still characterized by a high investment cost - in the model in order to satisfy the increasing energy demand. Furthermore, beyond the increasing trend, the costs are in average higher with the HREPV (15%) and HREW (15%). In other words, combining renewable technologies – PV and wind technologies- could allowed to reducing costs.

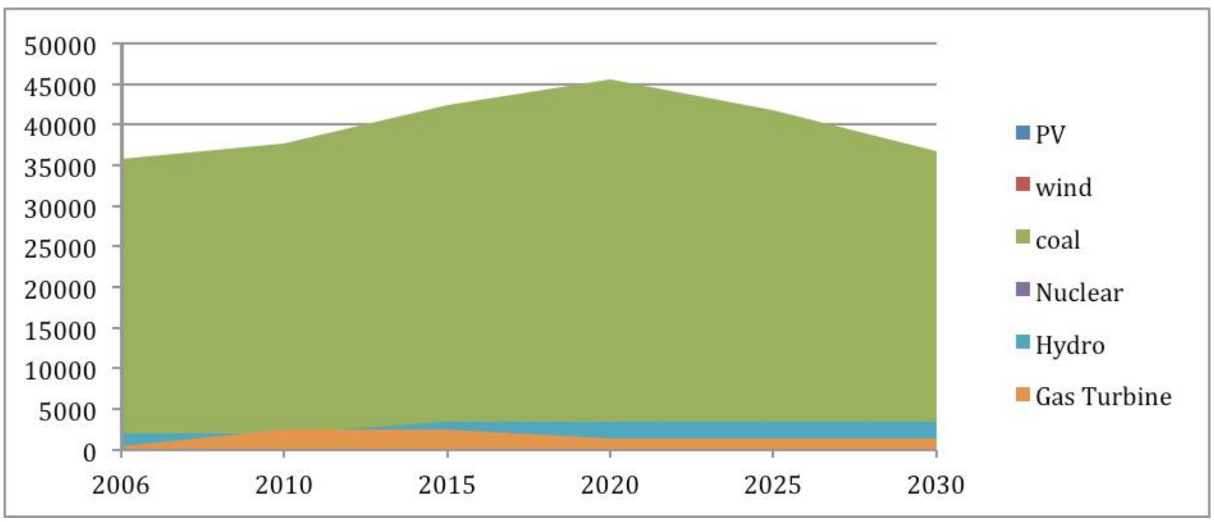

Figure 7: installed capacity under HRE30% (PV-wind) scenario for South Africa

For Senegal it can be seen that 15% of the total capacity installed comes from PV and wind under RE15% scenario in 2020, while 30% of the total capacity installed is renewable installed in 2030. It can be seen from table 9, that the share of diesel and steam resources decreases for all the three scenarios. The share of hydro - captured through the Manantali dam - decreases from 2006 to 2010 while it increases from 2010 to 2030 under HRE15%PV scenario. Under the HRE15%wind and HRE30%PVwind combined scenario, one can see always from the table 9 that the share of hydro is constantly decreasing from 2006 to 2030. The share of coal-based resources represents in average 16% of the supply source within the renewable deployment scenario, while the share of gas turbine remains the smallest within the supply structure among all the existing fossil fuel resource. Moreover in the case of Senegal, the costs increase in all the three scenarios and the costs are higher in 2030 for all HRE scenarios. Once can seen that from figure 8 that the diesel resource still dominates the electricity supply structure in Senegal in 2030 under the three different renewable deployment scenarios.

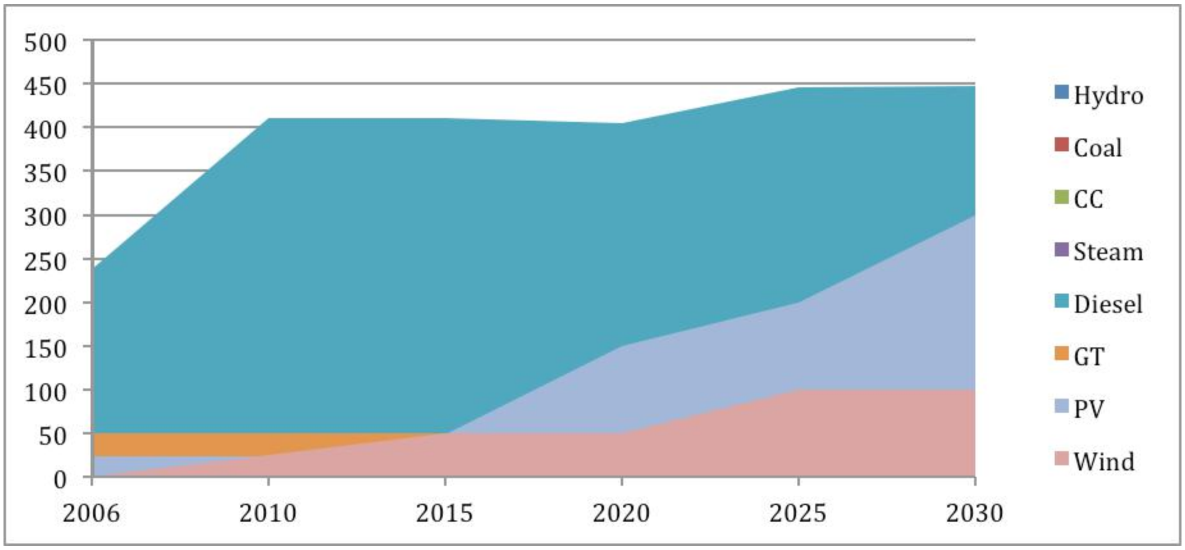

Figure 8: installed capacity under RE30% (PV-wind) for Senegal

5.5.c: Comparing scenarios

After having acknowledged the outcomes of the scenarios independently, we carried out comparisons following two dimensions: the costs and the environmental emissions under each one of the scenarios. When we compared the costs of different BAU and HRE scenarios, we found that the renewable technologies still remain costly compared to fossil-fuel technologies in the case of Senegal. In fact in 2010, 2020 and 2030 the investment required in order to diversify the supply chain with an involvement of renewable resources remains higher above the strategy to following the old supply pathway (figure 12). For South Africa we have found that the transition towards a renewable energy path is cost-competitive as evidenced by (Winkler, 2006). This situation could be explained by the two following points. On the one hand, this cost-competitiveness of renewable technologies in South Africa is probably the outcome of both the better learning process and the scale effects in this country. In fact South Africa has more technical experience in wind technology compared to Senegal (ref table 1 and 2). Moreover, South Africa has a better research basis. The research basis of renewable promotion in Senegal is mainly driven by ENDA-TM which follows a nongovernmental organization (NGO) rather than a research-oriented scheme. As the cost-competitiveness of renewable technologies remains driven by technological, market and institutional factors, countries having more researches and practical experiences have more opportunities to achieve diffusion of renewable technologies. Furthermore South Africa performed a scale effect while the energy required for the demand satisfaction is by far much higher compared to the case of Senegal. Therefore both the learning ability and the scale effect could be seen as vectors advantaging the cost-competitiveness of renewable technology transition in South Africa. On the other hand, South Africa is better endowed in renewable resources and employs better natural diversification of renewable resources compared to Senegal as well. For example in Senegal, the resource competitiveness of renewable resources remains only driven by solar PV while the wind speed required to running wind turbines efficiently is limited. The most profitable part where wind technology can be efficiently installed is just in the North coastal part of the country between Dakar and Saint Louis. Whereas in South Africa the higher wind speeds allows the country to generate an important share of renewable energy from wind technologies due to its large costal areas (DME, 2003). In terms of emissions both scenarios (BAU and RE) present environmental reduction although in South Africa the shape of this fall is much higher compared to the case of Senegal (figures 5 and 7). This can be explained by the higher energy supply of South Africa above Senegal (scale effect). Finally the transition towards sustainable electricity path presents advantages in terms of fossil-fuel use. In fact for both South Africa and Senegal, the fossil-fuel use is higher under the BAU above the HRE scenarios (figures 23 and 24). This finding indicates that an increase of renewable energy in the supply chain reduces the financial exits allocating to the payment of fossil-fuel bills. Moreover one can see that in terms of emission levels, for South Africa they are higher in 2020 under the HRE scenarios (HREPV (15%); HREW (15%) and HREPVW (30%)). But after 2020 the emission fall once we combine PV and wind technologies. In the case of Senegal, emissions increase from 2010 to 2030 with all the three HRE scenarios as well. As in the case of South Africa the combination of PV and wind reduces, also, the emission level in Senegal. As a conclusion, in terms of climate change policies, the hybrid approach – characterized by a combination of PV and wind - could provide good alternative by mixing the high learning rate effect of wind technologies and the endowment for solar resources in both South Africa and Senegal.

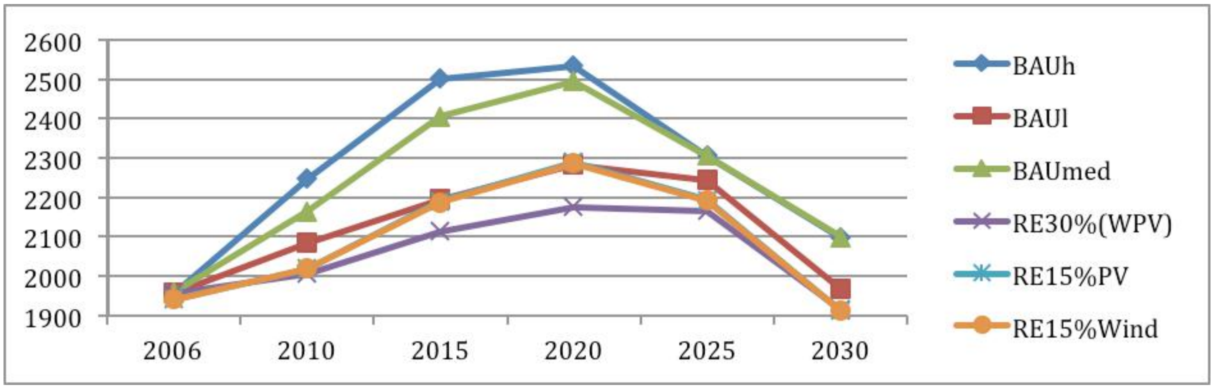

Figure 9: environmental emissions under different scenarios in South Africa

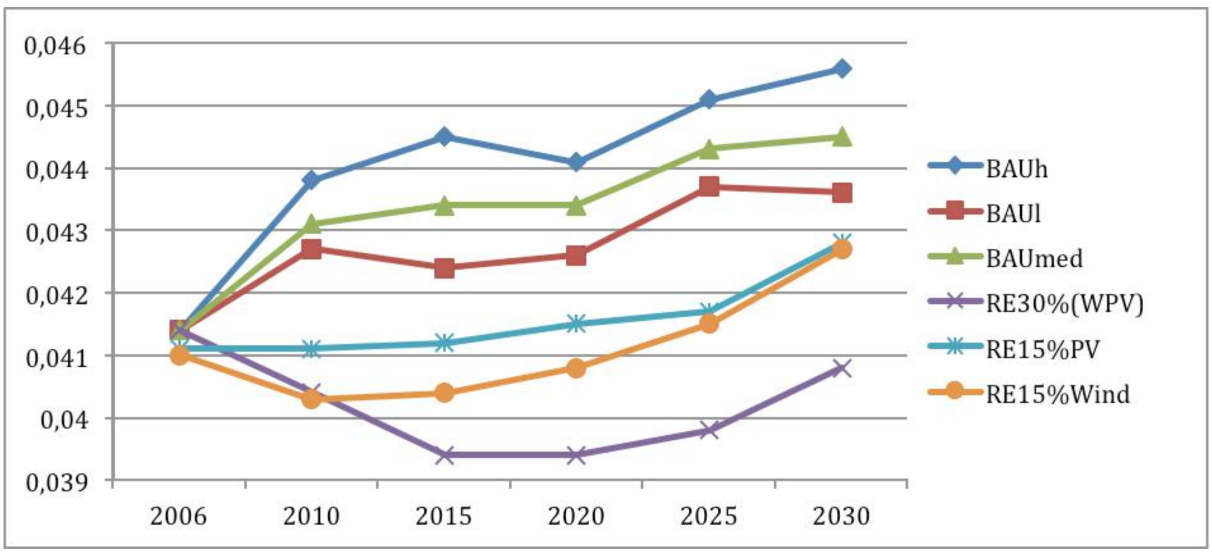

Figure 10: cost evolutions under the different scenarios for South Africa

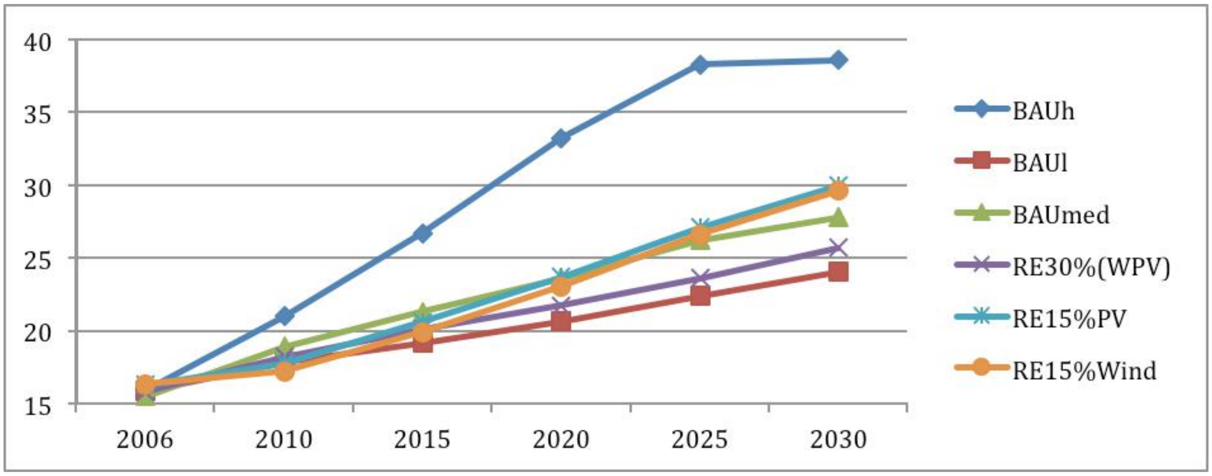

Figure 11: environmental emission under different scenarios for Senegal

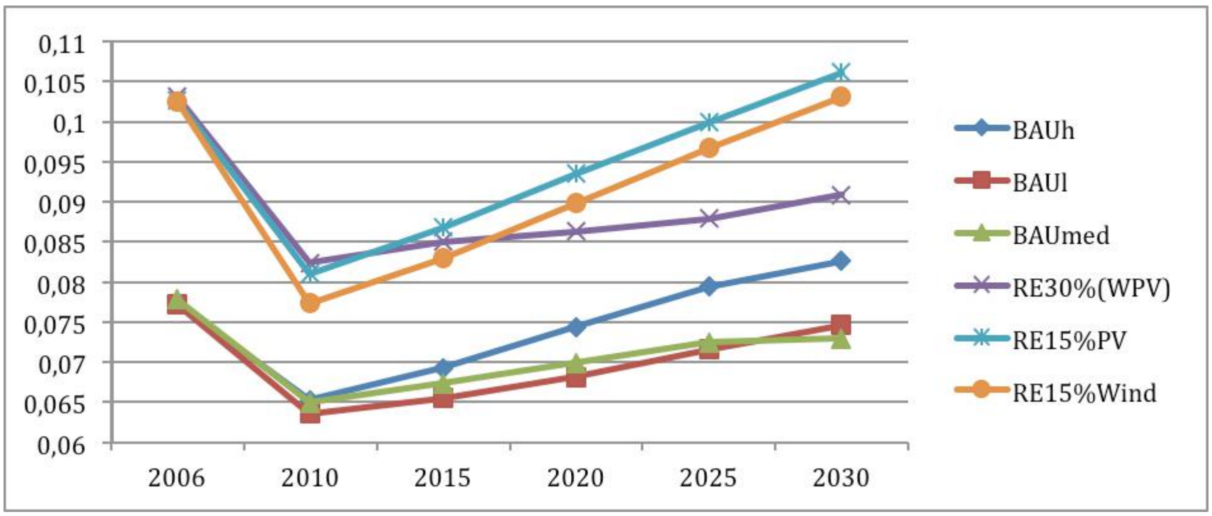

Figure 12: costs evolutions under the different scenarios for Senegal

Section 5.6: Conclusion

The objective of this paper has been to assess quantitatively the economic and environmental impacts of a transition towards sustainable electricity production in South Africa and Senegal. We found that clean technologies are cost-competitive in South Africa. In this framework, the advantage of clean technologies in South Africa can take effectively two forms: their use increases the diversification of electricity supplies while reducing the environmental emissions generated during the electricity production. For Senegal, renewable technologies are not yet cost-competitive. This finding indicates that, in a macro level, it is still more beneficial for Senegal to import fossil-fuel to producing electricity than using renewable technologies. However, these conclusions are based on costs, therefore neglect the extra advantages of using the renewable technologies. For example we have seen that for both South Africa and Senegal, the use of renewable technologies reduces both environmental emissions and fossil-fuel use. Once the policies internalizing environmental qualities are set up, clean technologies could probably become cost-competitive in both Senegal as well as South Africa.

However, although renewable technologies have shown their cost-competitiveness in south Africa, it could be interested to analyze how different policy incentives schemes could eventually strengthen their adoption in the South African context. The next chapter simulates a set of different incentives schemes for a promotion of renewable technologies. We differentiate between a carbon tax, price-based subsidy policies to renewable energy and the renewable energy portfolio standard. While taking into account the well endowment of coal-based resources in South Africa we differentiate fossil fuel sector from the renewable energy one. Moreover we assume that carbon taxes are applied to fossil fuel sector while both price-based subsidy policies and renewable energy portfolio standard are applied to renewable energy sector.

Chap 6 : Policy options for a transition towards renewable technologies in Developing Nations: Evidence from South Africa[39]

Abstract

The purpose of this paper is to investigate impacts of policy options for market penetration of renewable technologies in South Africa. Based on current debates about renewable energy policies and the comparative advantage of the country in terms of coal resources endowment we set up a framework focusing on renewable energy price subsidies, carbon tax and renewable energy portfolio standard. We assess - based on a simulation model throughout a linear programming approach - impacts of these policies on fossil fuel and renewable energy sectors throughout business-as-usual and a set of policy scenarios. The business-as-usual assumes that there are not policy options strengthening the diffusion path of clean technologies instead of a policy scenario where the mentioned above policies are carried out in order to promote clean technology deployment in South Africa. The results of our analysis show that once the coal-based resource endowment is integrated in the simulation process, only carbon tax and renewable energy price-based subsidies promote a transition towards a sustainable energy production, therefore reduce the associated environmental damage. Moreover we also show that in the case of carbon tax and renewable price subsidies, emission prices should be adequately scrutinized in order to guarantee a positive economic surplus.

JEL: Q42; Q47; Q48; H23; H32

Keywords: policy options; renewable energy; South Africa; technology policies

[39] This chapter is a slightly adapted version of Djiby-Racine Thiam " Policy options for a transition towards sustainable energy productions in developing nations" under review in Energy Policy

6.1: Introduction

The promotion of renewable technologies in developing nations has received large interests. On the one hand, the use of renewable technologies encourages a diversification of energy supply while reducing environmental emissions generated during the electricity production. On the other hand, it provides important impacts on economic issues because renewable energy generation does not require fossil fuels for their operation, so fuel price variations affect neither the quantity of electricity produced nor the performance of the energy system. Moreover the diffusion and adoption of clean technologies support a development of a lower carbon pathway and therefore strengthen abilities of developing nations to mitigate climate change.

However, although these impacts of renewable energy deployment are recognized, there are still few developing nations that are financially and strategically involved in their promotions. Most of renewable technologies in developing nations are carried out by international organizations through poverty reduction agendas. For example different financial mechanisms[40] have been set up, in international level, in order to increase the diffusion of clean technologies in developing nations. Although these existing financial mechanisms have interesting roles to play in the earlier stage of the renewable energy promotion[41] we argue that a sustainable promotion of clean technologies in developing nations requires an endogenous involvement of their respective

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[40] These financial schemes take multilateral as well as bilateral co-operations. The former is composed by international financial organizations such as World Bank (WB), United Nations Environment Program (UNEP), United Nations Development Program (UNDP) and International Energy Agency (IEA) etc. They provide financial supports to promote the deployment of clean technologies in developing nations. The latter, the bilateral cooperation takes a cooperation form between developing and industrialized nations through project development in order to increase the energy access in remote locations. In this perspective, some renewable promotion projects have been developed in large developing nations either though Clean Development Mechanisms (CDMs) or energy assistance policies

[41] In fact evidences have shown that some international initiatives such as CDMs have contributed to an increase of the share of clean technologies in many developing nations especially in Asia and Latin America. For example Boyd et al, (2009) provided an overview of the number of CDMs in different developing nations.

governments through a set of right public policies. Because basing renewable energy promotion solely on international financial agenda misses the importance role of involved developing countries that are better aware of local needs and responses, and thus are better able to implement technologies concomitant with the demand and economic potential of their surroundings (Ockwell et al, 2010; Knight et al, 2010).

In this context, the objective of this paper is to investigate a possible involvement of the South African government - throughout a set up of public policies - to promote the diffusion of renewable technologies. In doing so, we investigate impacts of policy options for a market penetration of renewable technologies. Three different policy options are considered: renewable energy price-based subsidies, carbon tax and the renewable energy portfolio standard. Renewable energy price-based subsidies assume an additional subsidy rate on renewable energy prices in order to guarantee secure payoffs to energy producers, the carbon tax commits coal-based electricity producers to a payment of a tax rate set by public authorities and the renewable energy portfolio standard commits a fix share of renewable energy to be produced by firms. The choice of the South African government to promote clean technologies is motivated by the following two points. First, the structure of the energy market in South Africa provides a room of maneuver in order to stimulate clean technology promotions. For example, an implementation of public policies remains possible because the electricity tariff is relatively weak comparing to the well endowment of the country in terms of natural resources, particularly coal-based ones. This comparative advantage ensures the country a tariff structure that is among the lowest in the world. Second, the country is involved in the promotion of clean energies. For example the Department of Mineral Energy (DME, 2008) outlined an ambitious program targeting an increase of renewable energy by 10.000 Gwh by December 2013. Moreover, the country reorganized its energy supply institution in order to facilitate the diffusion of clean technologies. A special letter promoting a large deployment of clean energy has been approved by the parliament during the past years. Finally, South Africa remains among the first African nation to have introduced the feed-law through a feed-in-tariff in order to guarantee a premium tariff to renewable producers. Since 2009, the country has adopted a law allowing renewable producers to sale their clean electricity generated in a higher price in the market.

To investigate impacts of policy options for market penetration of renewable technologies we provide a simulation model based on a linear programming approach through profit maximizations. The objective of these functions is to simulate the reaction of a representative firm according to policy options. The reaction of a firm is determined through the evolution of its profit and therefore the corresponding emission level. We also assess impacts of policy options on economic surplus. Moreover we differentiate impacts of policy options between fossil fuel and renewable energy sectors. Therefore, in the fossil fuel sector only a policy of a carbon tax is considered whereas in the renewable energy sector we assume renewable energy price-based subsidies and the renewable energy portfolio standard (RPS). Moreover in the fossil fuel sector we assume that electricity is entirely generated in using exclusively coal resources therefore no renewable resources are introduced, whereas in the renewable energy sector coal and renewable resources could be mixed to produce electricity. To assess economic efficiencies of policy options we compare business-as-usual (BAU) and renewable support policy scenarios. The business-as-usual scenario assumes that there are not policy options mobilized to promote a deployment of clean technologies instead of the renewable support policy (non - BAU) scenario where such policy options are considered.

The advantage of this type of analysis in developing nations is its ability to combine public policies requiring budget imputations and those requiring an improvement of market conditions. In this paper, a policy requiring budget imputations is renewable energy price-based subsidy whereas those requiring an improvement of market conditions are a policy of carbon tax and renewable energy portfolio standard (RPS). This distinction is important since it allows to combining “market” and “state” mechanisms in order to promote clean energy. Moreover, this distinction is also important because South Africa's fiscal resources are limited. Although, as mentioned above, the structure of energy market provides room for maneuvers to provide public policies promoting clean energy one must acknowledge that important social and economic programs require fiscal inputs as well. Which means optimal trade-offs must be made between different social requirements. However, as providing energy services is strongly linked to economic development, we argue that fiscal resources could be efficiently used in order to stimulate clean technology's adoption.

Studies having analyzed impacts of policy options for a promotion of renewable energy have been broadly carried out in industrialized nations (Langnis and Wiser, 2003; Neuhoff, 2005;

Klaasen et al, 2005; Morris, 2009; Mitchell, 1994; Lauber, 2004; Böhringer et al, 2009a; 2009b). For example Reiche and Bechberger, (2004) summarize policies used in the European Union to promote deployment of renewable technologies. They insisted on importance to include country-specific frameworks while designing optimal policy scenarios. These specific frameworks could take, for example, geographical, institutional and cultural forms. Fischer and Preonas (2010) analyze impacts of an overlapping policy instruments to promote a deployment of renewable technologies in the US electric sector. While considering four types of electricity generation: baseload technologies, natural gas, other fossil fuels and renewable energy, they analyze how the combination of emissions cap interacts with other policy options such as a carbon tax, fossil fuel tax and renewable subsidy with an endogenous emissions price. They argue that policies that raise the emissions price discourage coal-fired generation, while policies that lower the emissions price allow coal-fired generation to displace gas-fired electricity (Fischer and Preonas, 2010). They conclude that when emissions are capped, none of the overlapping policies can simultaneously disadvantage both kinds of fossil generation.

In the context of African nations empirical analyses of instruments promoting adoption of renewable energy are weakly documented in the literature. Winkler (2005) discusses an instrument that could be potentially used in South Africa to promote diffusion of renewable technology. He differentiates between three mechanisms: a feed-in-tariff, the renewable electricity portfolio standards and renewable obligation. He argues that the selection of instruments must be guided by the policy objectives. For example when the objective is to promote renewable electricity, but budget constraints are prioritized, fixing price through a feed law would help minimize costs. Whereas when the objective is to promote an environmental quality, regulating quantities through a portfolio standard gives the greatest certainty to decision-makers. Wolde-Ghiorgis (2002) investigates possible policies to stimulate adoption of renewable technology in rural areas in Ethiopia. To promote renewable energy adoption, he proposes an increase of the budget allocated to activities associated with renewable energy promotion and a modification of the existing institutional framework. Chidiezie and Ezike (2010) suggest the requirement of political will and collaboration to promote deployment of renewable technology in Africa. Edkins et al. (2010) assesse the effectiveness of renewable energy policies in South Africa by assuming what could be the renewable energy produced if the REFIT1 had been implemented earlier, before 2009 its starting period. They argue that based on the assumption that

South Africa implemented a REFIT in 2005 the renewable electricity target of supplying 10,000 GWh by 2013 would already have been reached in 2011. Thiam (2011) investigates policy options for market penetration of renewable technologies in Senegal. He identifies different tariffing mechanisms based on marginal, average and renewable energy premium tariffing schemes. His findings indicate that right support mechanisms could strengthen the sustainable deployment of renewable energy in developing nations. More recently Winkler and Marquard (2011) provided an analysis of economic implications of a carbon tax in South Africa. They argue that using a carbon tax could allow South Africa to mitigate climate change through a fall of greenhouse gas (GHG) emissions. Because a carbon tax would achieve this through two broad effects – a demand effect, reducing energy demand due to higher prices, and a substitution effect, with switching from more to less carbon- intensive fuels (Winkler and Marquard, 2011). Goldblatt (2010) compared cap-and-trade with carbon tax policies in the South African context following public policy criteria. Considering the market structure of the energy sector in South Africa he argues that carbon tax should be in some level preferred over cap-and-trade policies. Robb et al (2010) compared emission trade and carbon tax schemes to mitigate climate change in South Africa. They conclude that a tax is likely to be more appropriate in the immediate future, but that the choice could be different in the medium to long term, particularly if an international emissions trading framework is agreed upon. On the basis of the existing literature, the contribution of the paper is, first, to provide an empirical investigation of policy options to promote deployment of renewable technologies in South Africa. Second this article assesses impacts of policy options on social welfare in South Africa when carbon tax is combined with renewable energy price-based subsidies and renewable energy portfolio standard.

The paper is organized as fellows. Section 6.2 provides a theoretical foundation of a public intervention to promoting deployment of clean technologies in developing nations. Section 6.3 presents the architecture of energy structure in South Africa. After having outlined existing renewable deployment incentives in South Africa in section 6.4, we discuss the necessity to complete such incentives by additional mechanisms in order to strengthen the diffusion of clean technologies. Based on the provided additional mechanisms section 6.5 simulates their eventual economic and social impacts. Section 6.6 presents the results of the simulation. Concluding remarks are present in the last section (section 6.7).

Section 6. 2: Theoretical fundamentals of renewable technology promotion in developing nations.

The theoretical fundamentals of the public intervention to promote clean technologies could be linked to the influences of environmental economics and economics of technological change literatures. In fact, from the environmental economics perspective, the presences of externalities generated during the production of electricity from fossil-fuel resources lead to a sup-optimality of the economic system (Rabl et al, 2003; Owen, 2006). To correct such externalities environmental policies should be mapped, therefore facilitating a transition toward a more sustainable system. Such transitions could take generally two forms. First, it could take an end-of-pipe (EOP) process favoring an incremental addition of devices at the end of the production process that do not change the production pathway (Kempf, 2007). The transition towards a sustainable system could be carried out throughout a direct and a radical introduction of clean technologies. Therefore, from the beginning of the process, a new production design is generated embodying a direct use of renewable technologies. The environmental economics literature provides instruments allowing to stimulating the transition toward a sustainable energy system. One can distinguish two forms of instruments: the economic (Jaffe et al, 1999) and the command and control (CAC) instruments (Baumol and Oates, 1971). The economic instrument emphasizes the use of economic mechanisms to promote environmental-friendly technologies. These mechanisms could include, for example, tax policies, subsidies and tradable permits. The command and control instruments referred to as standard or regulations are used in order to promote renewable technologies. Different studies have analyzed impacts of these instruments on static efficiency (Kemp, 1997), environmental effectiveness (Hahn and Stavins, 1991) and dynamic efficiency (Milliman and Prince 1989) during a promotion of clean technologies. The main conclusion is that, although the instruments provide the same results in terms of efficiencies, their outcomes in terms of equity remain different (Downing and White, 1986).

Second, the involvement of public authorities to promoting clean technology's deployment can be influenced by the spillover effects derived from the technological change literature (Arrow, 1962; Nelson and Winter 1982; Fischer 2004). In fact, the innovation in energy sector generates spillover effects once a private firm undertakes alone investment costs. These spillovers could be exploited by competitors to increase their productivities and acquire new market shares without a contribution on innovation costs. In this context, investment in innovation sector could be compromise if there is not an intervention of public authorities. Therefore in order to promote an innovation in the sector public authorities should either protect the first investor during the early innovation process or just support entirely innovation costs. The promotion of renewable technologies could be hampered by the presence of spillovers if there are not public interventions. In the literature, these phenomena are referred for being the “double externalities” effects. Therefore in the literature, the presence of these market failures (double market failures) leads to an intervention of public authorities in order to promote the deployment of renewable technologies in developing nations.

Considering specificities of developing nations, additional reasons could be raised justifying a public intervention to promote environmental-friendly technologies. First, the promotion of clean technologies allows to strength the dynamic of the technological industry within the energy sector. In fact contrary to developed nations where clean technologies are introduced in order to substitute fossil-fuel technologies by new ones in order to tackle issues relating to global warming, in developing nations clean technologies are used in order to fulfill the lack of the required electricity producing technologies. In many developing nations electricity blackouts are caused by the lack of investments in the electric capacity production. For example in the selected developing nations (South Africa) using clean technologies could provide double “positive externalities effects”. It strengthens the technological capacity through an increase of investments in order to fulfill the investment gap observed in the electric sector, therefore avoiding the country those electricity blackouts observed in 2008. Moreover a public intervention to promote clean technologies in developing nations could probably facilitate the required coordination efforts between these nations and existing international financial schemes supporting clean technology’s diffusions. The existing top-down policy approaches following international assistance schemes could certainly provide insights in the short-term but presents shortcomings once a sustainable and a self-sufficient diffusion pathway of clean technologies is targeted in the long term. Public interventions in developing nations could therefore be seen as an instrument allowing them to take initiatives in order to strengthen - through bottom-up bases - their technological capacities. Finally, using clean technologies could facilitate the decentralized electricity supply in remote locations where grid-extension remains financially unsustainable. In fact while in many developing nations access to electricity, through the use of fossil-fuel sources, remains very limited, alternative means like clean technologies are seen as suitable options to provide electricity to populations, particularly those living in remote areas where grid-extension is financially unsustainable (World Bank, 2006; UNEP, 2010; Pegels, 2010). In this framework decentralized renewable options have been carried out in South Africa showing their economic interests (Deichmann et al, 2011). Moreover, being situated close to the point of demand renewable technologies use in decentralized options save costs relating to electricity transport and distribution.

Section 6.3: The energy sector in South Africa

The energy sector in South Africa is characterized by a high presence of fossil-fuel resources in the electric supply architecture (Fig 1). The majority of the fossil-fuel resource is composed of coal resource (Fig 2). For example, the coal represents more than 70% of the supply structure followed by nuclear (DME, 2008). The weight of coal into the electricity supply is justified by the well endowment of coal resources in South Africa. For example, DME (2008) argues that the country has at its disposal an important reserve of coal resources that are assessed to represent more than 55 billion tons. In the global level, the country has the world's sixth largest recoverable coal reserves.

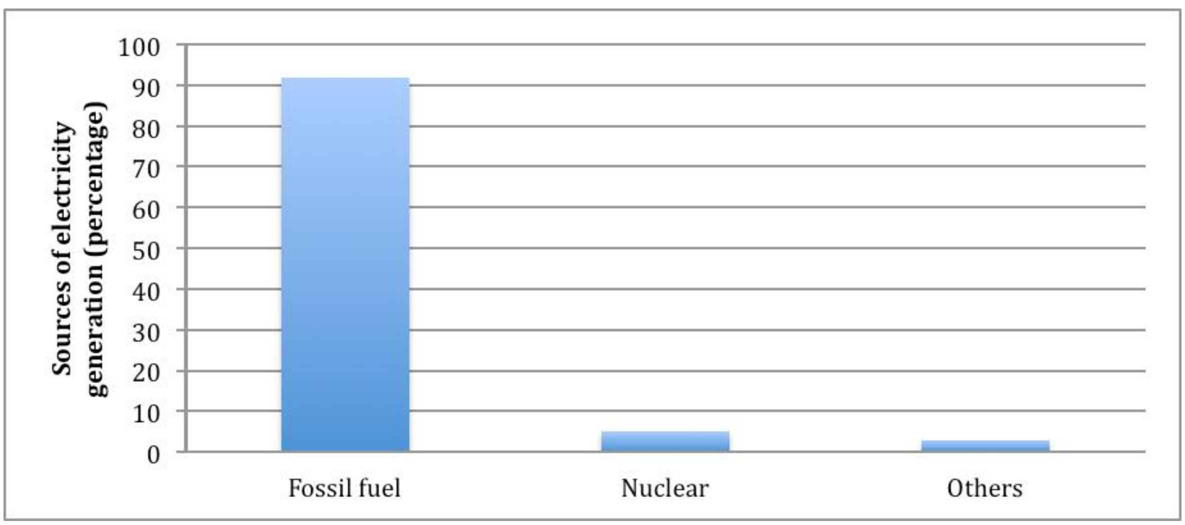

Figure 1: Sources of electricity supply (in percentage in 2008) in South Africa

Source: Observ'ER (2010)

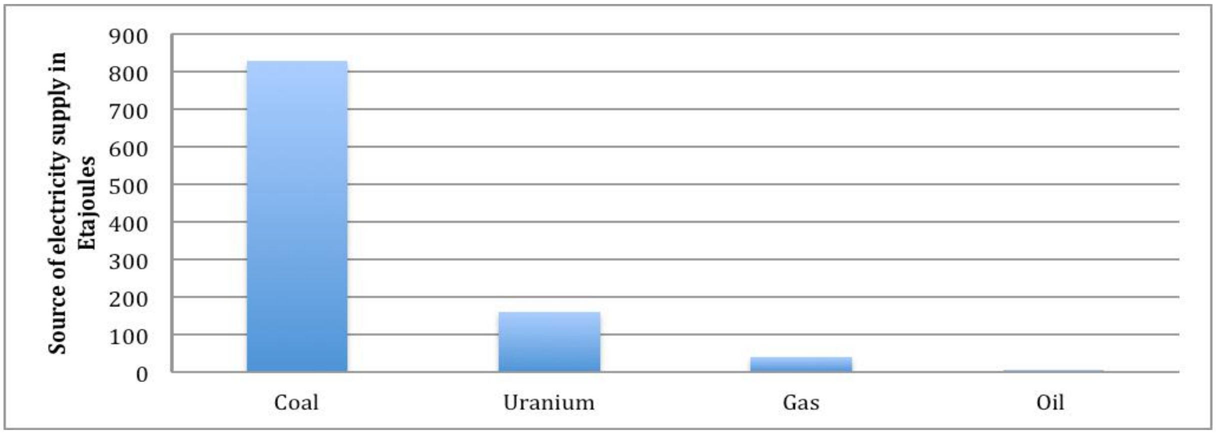

Figure 2: Share of energy resources in the electricity supply structure (in 2003)

Source: Kenny (2006)

The use of renewable energy remains broadly captured by hydropower representing the most important contribution of renewable resource (Figure 3). The large part of electricity from renewable resources, except hydropower, is focused on off-grid electrification aiming to increase clean energy in remote locations where grid-extension seems financially unsustainable (DME, 2003a; 2003b). The share of renewable energy into the structure of the electric supply represented 2,1% in 2008 (Observ'ER, 2010). To move to a low carbon pathway the country had initiated important initiatives in order to increase its share of renewable electricity. For example, the country is involving in two projects. The first project focuses on a 100MW wind power whereas the second project focuses on 100MW concentrating solar power. Figure 4 provides the average annual growth rate of renewable energy from 1998 to 2008 in South Africa.

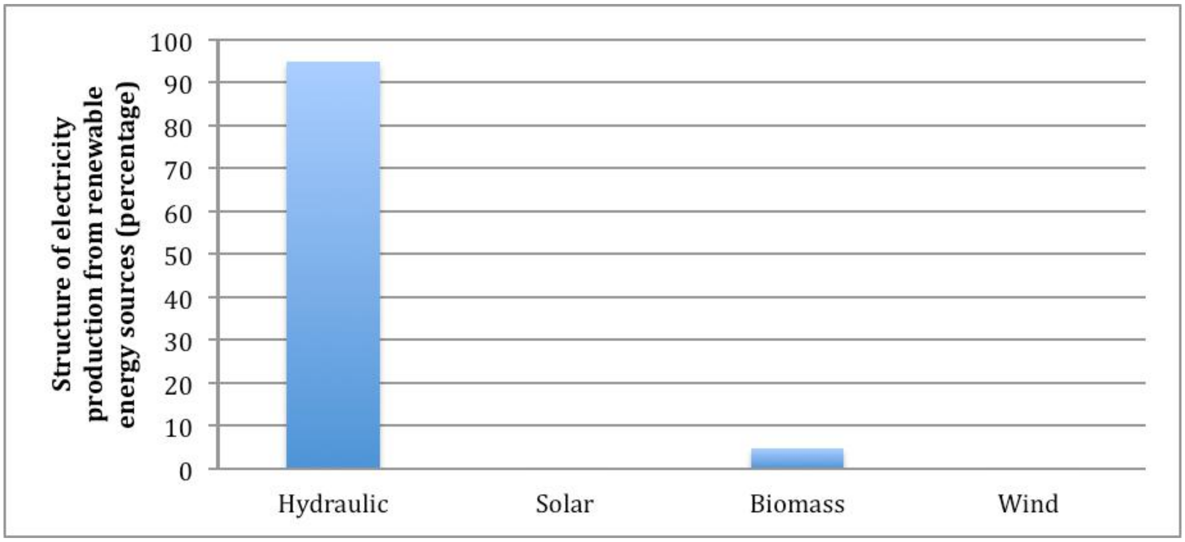

Figure 3: Structure of electricity from renewable resources 2008

Source : Observ'ER (2010)

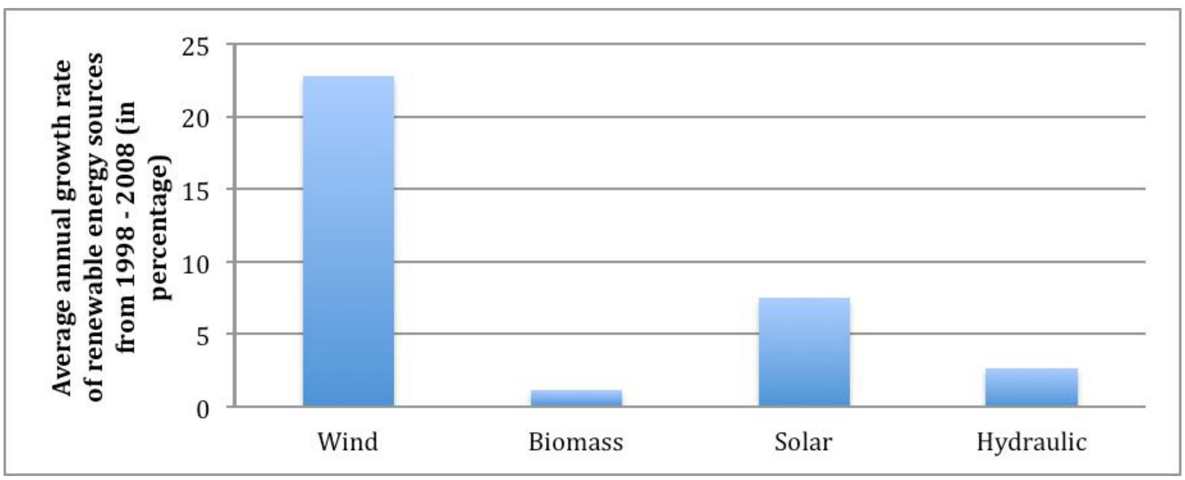

Figure 4: Average annual growth rate of renewable resources (1998 – 2008)

Source: Observ'ER (2010)

In terms of institutional structure, energy services are provided by ESKOM, a national state-owner company. Beyond ESKOM, municipalities are also involved in providing electricity through independent power purchase schemes. However, their market shares remain low compared to those held by ESKOM. The latter has a larger market share of electricity supply since it provides more than 90% of the electricity consumed in South Africa (UNEP, 2010). As the state-owner national company, it is responsible to providing electricity to populations in a lower tariff. In this framework, it is interesting to notice that the company tariff scheme was until recently among the lowest in the world. Figure 5 compares electricity tariffs between South Africa and other countries.

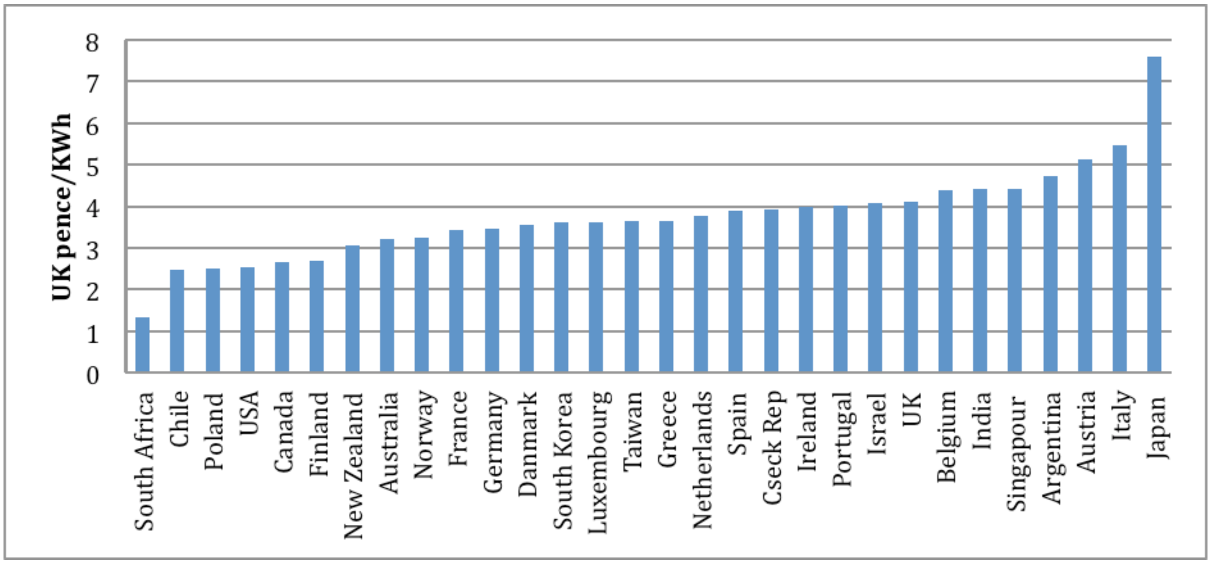

Figure 5: comparative prices of electricity in 2000

Source: Anton Eberhardt in Bond (2006)

Section 6.4: Policies of renewable energy promotion in South Africa

In South Africa, incentive mechanisms promoting a deployment of renewable energy could be sub-divided in two parts. First, renewable energies are promoted through existing international financing mechanisms encouraging a diffusion of clean technologies in developing nations. In fact, since the set of Kyoto protocol market mechanisms - clean development mechanisms (CDM) - have been advanced in order to increase the diffusion of clean technologies in developing nations as well as to reduce environmental emissions in developed nations. In this context the country has received CDM projects in the electric sector[42]. Second, policies promoting clean technologies in South Africa take internal measures raised through feed-in-tariffs. In fact since 2009, the country has introduced a feed-in-tariff schedule in order to strength the diffusion of clean technologies. The feed-in-tariff (FiT) implies a certified purchase by

[42] For example Boyd et al (2009) provided an overview of CDM's projects in South Africa

utilities of electricity produced in defined areas from renewable technology at a fixed tariff during a certain time. It is defined by the government and reflects the price of electricity in kWh that the local company must pay to the renewable energy producer. Table 1 provides the structures of the feed-in-tariff in South Africa.

Table 1: renewable energy feed-in-tariff schedule in South Africa

REFIT	Technology	R/kwh
Phase I	CSP	2.10
	Wind	1.25
	Small hydro	0.94
	Landfill gas	0.90
Phase II	CSP through without storage	3.14
	Large scale grid-connected PV systems (> 1MW)	3.94
	Biomass solid	1.18
	Biogass	0.96
	CSP tower with 6 hours per day storage	2.31

Source: Edkins et al (2010)

However although these incentive mechanisms - CDMs and feed-in-tariff - are expected to provide an increase of renewable energies (DME, 2008; Winkler et al, 2010), we believe that additional incentive mechanisms should be mobilized in order to strength the diffusion of renewable technologies in South Africa. Complementing existing incentive mechanisms by new ones can be justified in two levels. First, empirical evidences around the world (Reiche 2004; Neuhoff, 2005; Mitchell 1994; Thiam, 2011) have shown that a mix of strategies has been carried out in many part of the world in order to increase the share of renewable energy. Moreover, mixing strategies allows a country to combine advantages and drawbacks of all existing incentive mechanisms. While the deployment of renewable technologies follows market, technological and institutional specificities, policies strengthening their diffusion should take into account all these components. Second, a mix of mechanisms allows South Africa to attenuate the share of the budget devoted to clean energy promotion in integrating market mechanisms. In fact, as putting feed-in-tariff requires fiscal resources[43] and the country, as mentioned above, faces fiscal

[43] This assumption is no more verified once a price response with regard to an increase of clean electricity price is considered. But in the context of South Africa, where there are still many poor people living in peri-urban and remote locations an increase of the electricity tariff can be seen as an inefficient means to reduce inequality in the country. Moreover with the targets of the government to increase the energy

limitations, alternative market-based incentives could provide alternative means to promote a deployment of renewable technologies. Therefore combining existing incentives with new ones provides a more market-oriented pathway of clean technology diffusion. Because, although actions of public incentives in earlier stages of renewable technology deployment is well recognized, it is also admitted that after having reduced risks and uncertainties it is optimal to facilitate competition between technologies through market-based incentives (Rai et al, 2009). Therefore, the paper simulates impacts of additional policy options for a market penetration of clean technologies in South Africa.

Section 6.5: Model framework

An end-oriented optimization method is carried out to analyze impacts of policy options for market penetration of renewable technologies in South Africa. We develop a linear programming approach in which the objective is to maximize profits. We differentiate between fossil fuel and renewable energy sectors and simulate three different policy options namely renewable energy price-based subsidy, a carbon tax policy and renewable energy portfolio standard. In the fossil fuel sector we assume that electricity is entirely generated in using exclusively coal resources whereas in the renewable energy sector coal and renewable resources could be mixed. We provide a supply-oriented framework while the characteristics of electricity generating technologies are well specified. Our model is based on the work of Fischer and Newell (2004). At the distinction from the above mentioned authors we differentiate between the abatement cost[44] and the electric generating technology costs. This distinction is understandable once a partial regulator imposing an abatement cost to the firm as long as coal-based resources are used as input during the electricity generation is considered. Moreover, in our model we assume that both fossil fuel and renewable sectors are complementary. Finally, we integrate the coal-based comparative advantage of South Africa into the modeling process since the coal resource in

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access for populations and to reduce the economic inequality within the country a transfer of feed-in-tariffs to consumer's bills will comprise such targets. Therefore we consider that the feed-in-tariff is entirely funded by public resources.

[44] We assume that abatement costs refer to those raised through an incremental end-of-pipe process. This assumption allows us to bypass the usual tradeoff between the marginal abatement cost and the costs of introducing renewable technologies.

South Africa remains one of the highest in the world. Therefore the transition towards a sustainable production pathway in South Africa includes, no matter how the evolution of clean technologies are, at least a certain percentage of coal resources in the electric production process. Figure 6 shows the overview of the model.

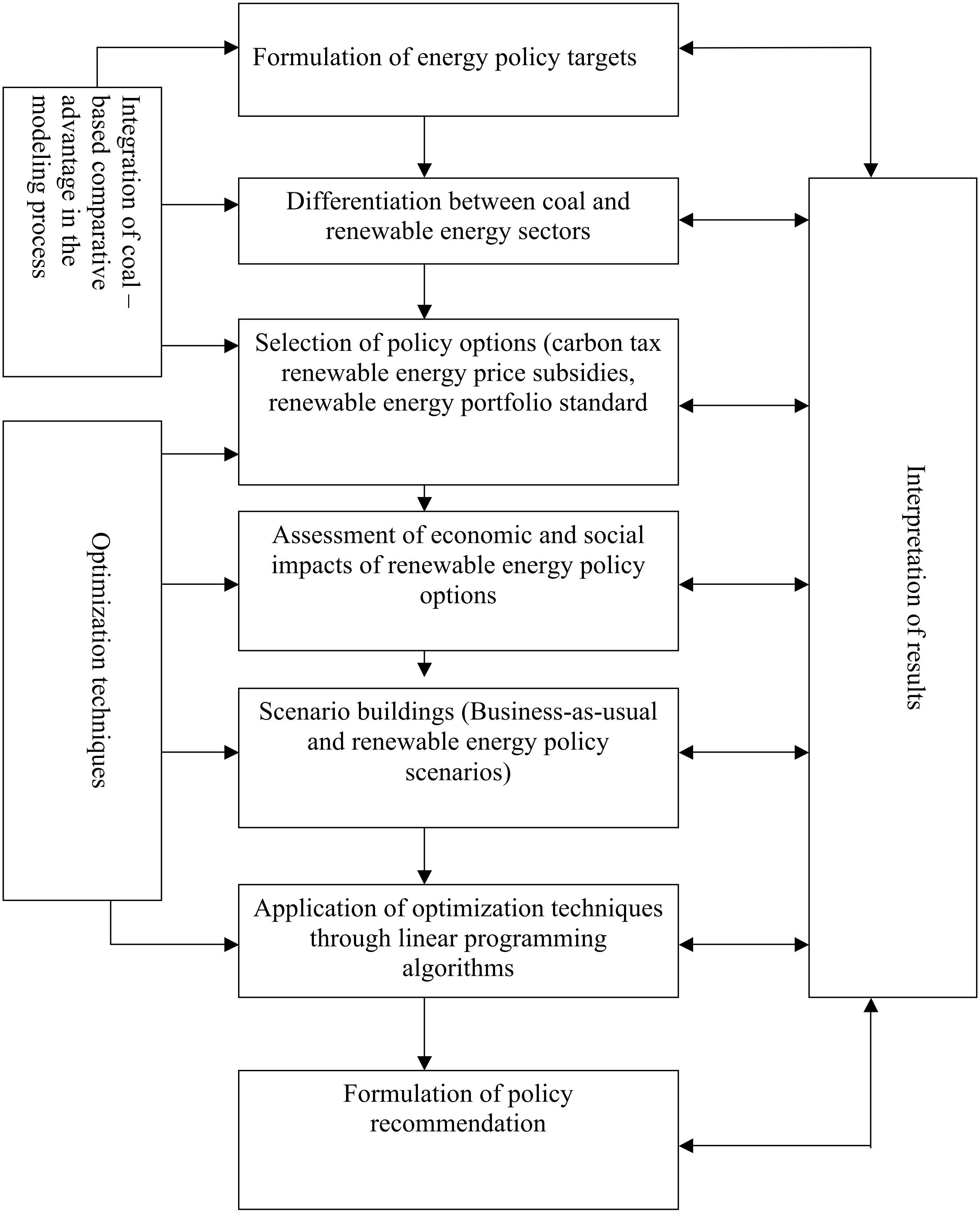

Figure 6 : The overview of the modeling process

6.5.a: Model structure

$$Max(\Pi_R + \Pi_c) \quad (1)$$

Subject to

$$q_R \leq \left(\frac{1}{\hat{\beta}} - 1\right) q_c \quad (2)$$

$$w_c \geq w_c^* \quad (3)$$

where Π_R and Π_c represent profits of a representative firm with renewable and coal resources respectively. Therefore *R* represents the renewable technologies. Moreover we assume that q_R and q_c represent the renewable and coal-based energy generated respectively. $\hat{\beta}$ represents the imposed share of coal-resources in the model, w_c the emission intensity of the fossil-fuel sector and w_c^* the emission intensity once renewable energy sector is considered. Equation (2) integrates the comparative advantage of coal resources in South Africa. It assumes that, although renewable policy options are raised, South Africa keeps a percentage of energy from coal resources in the supply portfolio. Equation (3) takes into account the environmental dimension by integrating emission intensity into the modeling process. We assume that emission intensities are higher when only fossil-fuel sector is considered compared to the situation when we introduce renewable energy in the modeling process. The model is calibrated for the year 2025 in order to take into account forecasts of energy situations in South Africa.

6.5.b: The fossil-fuel sector

The fossil fuel sector assumes that electricity is produced exclusively from coal resources therefore no renewable resources are introduced. Moreover we assume that only carbon tax (emitted prices) is considered as a policy option. Therefore, if one assumed that θ_c represents the tax value applied to coal resources the profit of the representative firm could be represented as follows.

$$\Pi^{c}/_{\theta_c} = (p_c - \varepsilon - \theta_c)q_c - H_1[I_c; q_c] \qquad (4)$$

with

$$H_1[I_c; q_c] = \frac{I_C}{(1+r)^T} + \delta q_c^2 \qquad (5)$$

where $\Pi^{c}/_{\theta_c}$ is the profit under the fuel sector with a carbon tax policy, p_c the price of electricity from coal resources, ε represents the marginal cost of the end-of-pipe abatement process, q_c coal-based electricity generated. Equation (4) assumes that once coal resources are used in the production process, firms are therefore, committed by a regulator to reduce environmental pollutants through an introduction of a carbon tax and/or an increase of end-of-pipe abatement cost. The carbon tax is applied to the coal-based energy generated. The function $H_1[I_c; q_c]$ represents the cost of a coal-based technology composed by capital and operating and maintenance costs. Equation (5) shows the structure of this cost, where r is the discount rate, T the lifetime of our analysis, I_C the initial capital cost and δ a parameter with $0 \prec \delta \prec 1$. The firm maximizes profits with respect to output yielding the following first-order conditions:

$$\frac{d\Pi^{c}/_{\theta_c}}{dq_c} = 0 \Rightarrow p_c = \theta_c + \varepsilon + 2\delta q_c \qquad (6)$$

Equation (6) shows the evolution of the market price in the fossil fuel sector. Moreover, following (Fischer et al, 2004) we assume that the total emission E_c could be represented in the following terms (Equation 7). Equation (8) represents the damage function.

$$E_c = w_c \times q_c \qquad (7)$$

$$D_c = \frac{1}{2\psi} E_c \qquad (8)$$

6.5.c: The renewable energy sector

The renewable energy sector assumes that electricity is produced through a combination of coal and renewable resources. We consider two different policy options: the renewable energy price-based subsidy and the renewable energy portfolio standard. Moreover, as mentioned above, we assume that the emission intensity while integrating renewable resources w_c^* is lower than w_c the emission intensity performed under the fossil-fuel sector. This assumption is due to the fact that environmental pollutants generated during a combination of renewable and fossil-fuel resources remain lower compared to environmental pollutants generated if only fossil fuel is used. In the renewable energy sector the idea of energy transition requires an energy supply mix through an use of both coal as well as renewable resources. Therefore the profit of a firm is the sum of profits from renewable and coal sources. This is confirmed by Equation (2) where a percentage $\hat{\beta}$ of coal resource is used. Therefore under the renewable energy price-based subsidy, the profit of renewable sources is $\Pi R/_S = (p_R + s)q_R - H_2[I_R; q_R]$ and the profit of coal sources is $\Pi C/_S = (p_c - \varepsilon)q_c - \theta_c\left(\beta - \hat{\beta}\right)q_c - H_1[I_c; q_c]$. The total profit is, therefore, the sum of these two profits $\left(\Pi R/_S + \Pi C/_S\right)$. Where p_R represents the renewable energy price, s the subsidy rate, q_R the renewable energy generated and $H_2[I_R; q_R]$ the cost of renewable technologies. Like the fossil fuel sector in the renewable energy sector the cost is the sum of capital and operating and maintenance costs $H_2[I_R; q_R] = \frac{I_R}{(1+r)^T} + \eta q_R^2$ where I_R is the initial capital cost, r the discount rate and η is a parameter with $0 \prec \eta \prec 1$. Moreover the difference between $\theta_c\left(\beta - \hat{\beta}\right)q_c$ represents taxes paid anytime when the firm produces more than the initial required $\hat{\beta}$% of energy from coal resources, where β is the percentage of a possible coal-based energy generated. This expression allows us to capture opportunist behavior of firms in the renewable energy sector. According to the value of β three scenarios are possible: $\beta \succ \hat{\beta}$ where the energy from coal resources is higher than its percentage required, $\beta \prec \hat{\beta}$ where the energy from coal resources is lower than its percentage required and $\beta = \hat{\beta}$ where the firm generates exactly $\hat{\beta}$% of electricity from coal resources. To simplify our interpretation we always assume that $\beta = \hat{\beta}$, therefore a penalty is not imposed to the firm due to its over production of coal-based electricity. Like the renewable energy price-based subsidy, the profit of renewable energy sources in renewable energy portfolio standard is $\Pi^{R}/_{RPS} = p_R x(q_R + q_c) - H_2[I_R; q_R]$ whereas the profit of fossil fuel sources $\Pi^{c}/_{RPS} = (1-x)(q_c + q_R)\left[p_c - \varepsilon - \theta_c\left(\beta - \hat{\beta}\right)\right] - H_1[I_c; q_c]$. Therefore the total profit is the sum of profits from both renewable and coal sources $\left(\Pi^{R}/_{RPS} + \Pi^{c}/_{RPS}\right)$. Where ($x$) represents the percentage of renewable energy that should be generated otherwise (1-x) should be generated from fossil fuel resources. The firm maximizes profits with respect to outputs, yielding the following first-order conditions

$$\frac{d\left(\Pi^{R}/_{s} + \Pi^{c}/_{s}\right)}{dq_R} = (p_R + s) - 2\eta q_R = 0 \tag{9}$$

$$\frac{d\left(\Pi^{R}/_{s} + \Pi^{c}/_{s}\right)}{dq_c} = p_c - \varepsilon - \theta_c\left(\beta - \hat{\beta}\right) - 2\delta q_c = 0 \tag{10}$$

$$\frac{d\left(\Pi^{R}/_{RPS} + \Pi^{c}/_{RPS}\right)}{dq_R} = (1-x)\left[(p_c - \varepsilon) + \theta_c\left(\beta - \hat{\beta}\right)\right] + xp_R - 2\eta q_R = 0 \tag{11}$$

$$\frac{d\left(\Pi^{R}/_{RPS} + \Pi^{c}/_{RPS}\right)}{dq_c} = (1-x)\left[(p_c - \varepsilon) - \theta_c\left(\beta - \hat{\beta}\right)\right] + xp_R - 2\delta q_c \tag{12}$$

6.5.d: Consumer perspectives

The consumers are represented through the utility function. Following Goulder (2005) we assume that the total utility function is represented in the following form.

$$U(C_i, D_i) = C(p_i) - D_i \quad (13)$$

where C_i represents the consumption of the product i (electricity) with $i = R + c$ representing the combination of electricity from renewable and coal resources, D_i the environmental damages and p_i the electricity price. Therefore the consumer surplus could be represented in the following form:

$$CS = \int_{p}^{+\infty} C(p)dp \quad (14)$$

Furthermore in order to assess impacts of incentive mechanisms on economic surplus we define the following equation (15) capturing the variations of different components such as profits, consumer surplus, environmental damage and the net income. We assume that ΔZ represents the transfers measured by the difference between the tax revenues and the cost of the subsidies.

$$\Delta W = \Delta\Pi_R + \Delta\Pi_c + \Delta CS - \Delta D_i + \Delta Z \quad (15)$$

where

$$\Delta Z = \theta_c q_c - s q_R \quad (16)$$

Therefore in combining equations (4-8) and (13 - 16) we determine the emission price with which the firm yields same payoffs.

$$\theta_c / \Pi^{c}/_{\theta_c} = \left(\Pi^{c}/_{s} + \Pi^{R}/_{s}\right) \Rightarrow \theta_c = \frac{\left(1-\hat{\beta}\right)\left(p_R + s - AC_R\right)}{\hat{\beta}\left(\beta - \hat{\beta} - 1\right)} \quad (17)$$

$$\theta_c / \Pi^{c}/_{\theta_c} = \left(\Pi^{c}/_{RPS} + \Pi^{R}/_{RPS}\right) \Rightarrow \theta_c = \frac{1}{(1-x)\left(\beta - \hat{\beta}\right) - \beta}\left[p_R x + (p_c - \varepsilon)(1-x) - \left(1-\hat{\beta}\right)AC_R\right] \quad (18)$$

with

$$AC_R = \frac{H_2[I_R; q_R]}{q_R} \quad (19)$$

where AC_R is the average cost of renewable technologies.

Moreover in combining equations (4-16) we determine the value of carbon prices ensuring a positive economic surplus through the three different policy options.

$$\psi^{\theta_c}/_{\Delta W \succ 0} =$$

$$Min\psi^{\theta_c}/_{\Delta W \succ 0} / \psi \succ \frac{1}{2}\left[\frac{w_c}{(p_c-\varepsilon)-AC_c+\frac{1}{2}q_c\left(2-\hat{\beta}\right)^2-s\left(1-\hat{\beta}\right)}\right] \quad (20)$$

$$\psi^{s}/_{\Delta W \succ 0} =$$

$$Min\psi^{s}/_{\Delta W \succ 0} / \psi \succ \frac{1}{2}\left[\frac{w_c}{\left(1-\hat{\beta}\right)\left((p_R+s)-(p_c-\varepsilon)AC_R-s\right)-\theta_c\left(\beta-\hat{\beta}\right)-AC_c+\frac{1}{2}\left(2-\hat{\beta}\right)^2 q_c}\right] \quad (21)$$

$$\psi^{RPS}/_{\Delta W \succ 0} =$$

$$Min\psi^{RPS}/_{\Delta W \succ 0} / \psi \succ \frac{1}{2}\left[\frac{w_c}{\left(1-\hat{\beta}\right)(p_R x-AC_R-s)+\left(p_c(1-x)-\varepsilon\right)-\theta_c\left(\beta-\hat{\beta}-1\right)-AC_c+\frac{1}{2}\left(2-\hat{\beta}\right)^2 q_c}\right] \quad (22)$$

The variables $\psi^{\theta_c}/_{\Delta W \succ 0}$, $\psi^{s}/_{\Delta W \succ 0}$ and $\psi^{RPS}/_{\Delta W \succ 0}$ represent emission prices ensuring at least a positive value of the economic surplus under the different policy options.

6.5. e: scenario making

To analyze impacts of renewable energy policies we differentiate between profits under business-as-usual (BAU) and renewable energy policy scenarios. Indeed the business-as-usual scenario assumes that there are not policy options mobilized in order to promote the deployment of renewable technologies in South Africa. In such a situation in both fossil fuel and renewable energy sectors profits would not include corresponding policies considered namely a policy of carbon-tax, a price-based subsidy of renewable energy and a renewable energy portfolio standard. In the second scenario in which renewable deployment policies are considered, we introduce corresponding policies in the profit and analyze their evolution. Equations (23) and (24) represent profits of fossil fuel and renewable energy sectors throughout a business-as-usual scenario.

$$\Pi^{BAU}/_{fossil-fuel} = (p_c - \varepsilon)q_c - H_1[I_c; q_c] \quad (23)$$

$$\Pi^{BAU}/_{renewable} = p_R q_R - H_2[I_R; q_R] \quad (24)$$

where $\Pi^{BAU}/_{fossil-fuel}$ is the profit under the business-as-usual scenario of the fossil-fuel sector and $\Pi^{BAU}/_{renewable}$ represents the profit under the business-as-usual scenario of the renewable energy sector. Equation (4) represents the profit under the policy scenario of the fossil-fuel sector whereas $\left(\Pi^{R}/_{s} + \Pi^{c}/_{s}\right)$ and $\left(\Pi^{R}/_{RPS} + \Pi^{c}/_{RPS}\right)$ are profits under the policy scenario of the renewable energy sector.

6.5.f : *Case study*

As indicated earlier, the case study is focused on South Africa. The data considered are focused on the structures of renewable technology devices in the country (Table 2). Table (2) identifies the selected electricity producing technologies based on technico-economic characteristics of the energy market in South Africa. (Ti) are the selected technologies with T_c representing the coal technology while T_{R1} and T_{R2} are renewable technologies respectively. We differentiate two different renewable technologies in order to integrate cost differences between technologies[45]. Table 3 provides the required data in order to calibrate the model.

Table 2: data on costs of technologies

Technologies (Ti)	Capacity (MW)	Costs ($US/KW)
T_c	25	570
T_{R1}	3	3000

[45] One can think about the cost difference between wind and solar technologies.

T_{R2}	3	3500

Source: Data are selected according to the market of renewable technologies in South Africa

Table 3: data on technical features

w_c	347
p_c	3
p_R	3,94
$\hat{\beta}$	0,7
r	0,1
δ	0,05
η	0,05
ε	0.5

Source: Parts of these data (p_c, p_R, w_c, r) are selected from the existing literature. The rest has been set up in order to calibrate the simulation basis.

The simulation of policy options for market penetration of renewable technologies allows to investigating potential impacts of a set of public policies to increase the share of renewable resources into the electricity supply. For a country like South Africa with a higher ambition to promote a deployment of renewable energy a trade-off among different policy options is necessary in order to provide optimal solutions. To take into account the coal comparative advantage of South Africa we combine renewable and fossil-fuel energy sources. To analyze impacts of renewable energy promotions in South Africa we perform scenario analyses. The scenarios developed differentiate between coal and renewable energy sectors. In the coal sector we assume that all the electricity is generated from coal resources and no renewable resources are introduced in the electricity production. Whereas in the renewable energy sector we assume that a combination of coal and renewable resources are carried out in order to generate electricity. Therefore our transition process takes an evolutionary process in the sense that introducing clean technologies could only be made with a combination of existing coal resources. Furthermore we introduce renewable policy options according to the differentiation of these two sectors. For example in the fossil fuel sector only a carbon tax is considered whereas in the renewable energy sector we assume that renewable energy price-based subsidy and renewable energy portfolio standard are considered. The carbon taxes are applied to environmental pollutant generated during the electricity production from coal resources. We capture environmental pollutants by CO2 emissions. We assume that for each unit of CO2 emitted the firm is charged to pay a percentage of a tax captured by θ_c. In the renewable energy sector we assume that a share (s) of subsidy is added to the renewable electricity price in order to guarantee a secure payoff to renewable producers. Finally the renewable energy portfolio standard commits a percentage (x) of electricity to be produced from renewable resources. However to analyze efficiencies of policy options for market penetration of renewable technologies two pre-requirement should be met: the impact of local acceptance on technology diffusion and the ability to improve the learning process in order to strengthen the learning-rate of renewable technologies. The social acceptance can be driven by supply as well as demand sides. In the supply side the social acceptance of technology diffusion emphasizes on the ability of actors (firms) to change their production process through an integration of new technological and organizational paradigms. In the case of consumers, the social acceptance emphasizes on ability of consumers to change their consumption pathway through an adoption of a sustainable consumption design. We assume that the social acceptance of these new technologies is complete. All firms are ready to participate in an energy substitution, which will reduce their dependency on fossil fuel energy, protect the environment and promote the energy transition, once policy options are raised. Therefore we do not emphasize distinctions between socio-political acceptance, market acceptance and community acceptance as argued by Wüstenhagen et al., (2007). We assume that the acceptance is exogenous. The second requirement can be easily assume in South Africa. Because the ability to improve the learning process can be describe as a dynamic of the research and development in the renewable energy sector. Which is well performed in the South African context because one can acknowledge that there are different experiences allowing the nation to capture and improve the learning process of clean technologies.

Section 6.6: Results

The results of our analysis show the evolutions of profits under business-as-usual and renewable energy policy scenarios. One could acknowledge that, as expected, profits are higher when there is not an intervention in order to promote a deployment of renewable technologies. Figures 7, 8 and 9 show evolutions of profits under carbon tax, renewable energy price-based subsidies and renewable energy portfolio standard within business-as-usual as well as renewable policy scenarios. Figure 7 shows that with carbon tax profits are higher under BAU and constant over time whereas under the renewable energy scenario, profits are lower and they decreases according to an increase of the tax rate. One could remark also that once incentive mechanisms are introduced, profits decrease until a threshold value under which there is not an investment in renewable technology generation. Figure 8 shows an increase of profits, once subsidy policies are raised to promote a deployment of renewable technologies. Moreover one could remark that without subsidies, firms won't invest in renewable technology. Figure 9 shows evolutions of profits under the renewable energy portfolio standard. It tells us that such an investment will not be carried out because it provides a negative profit in both cases (BAU as well as renewable energy policy scenarios). One can remark also that an increase of the renewable standard deepens the profit loss as long as an improvement of technological learning rate is not observed in renewable energy industry. With renewable energy portfolio standard, we put forward the characteristics of the market by stimulating competition among different potential producers in order to provide clean energy. But as the marginal cost of clean technologies remains still higher compared to fossil fuel technologies, market outcomes diverge from the equilibrium outcome.

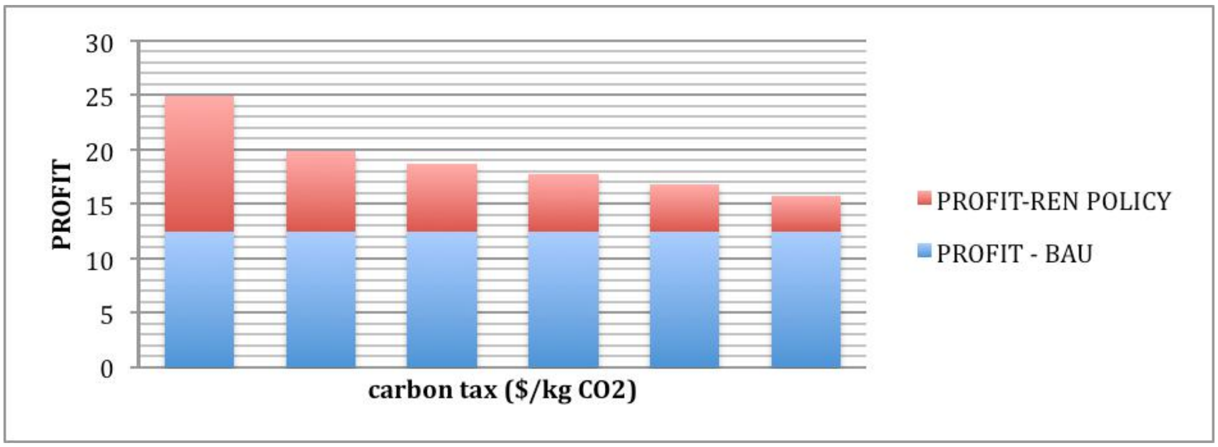

Figure 7: Evolution of the profit under carbon tax policies

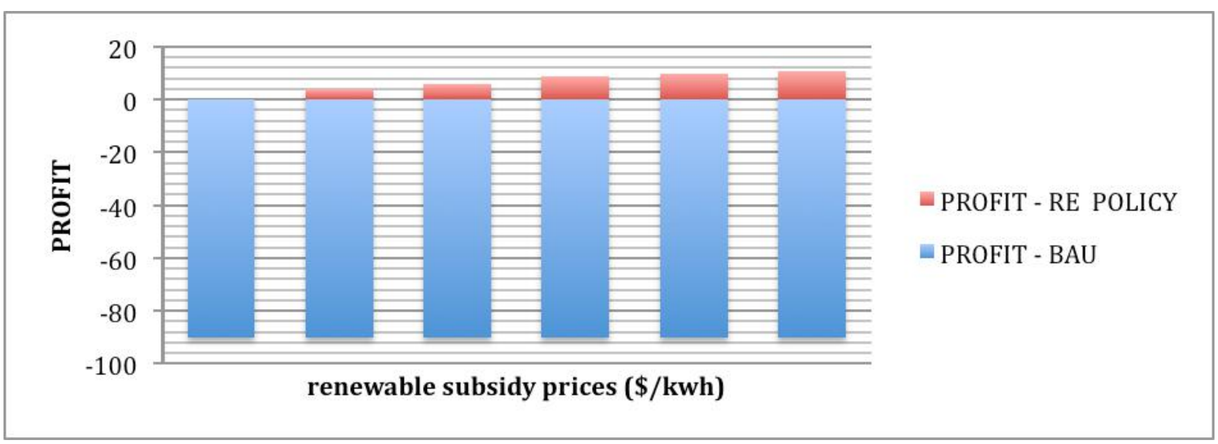

Figure 8: Evolution of the profit under price-based subsidy policies

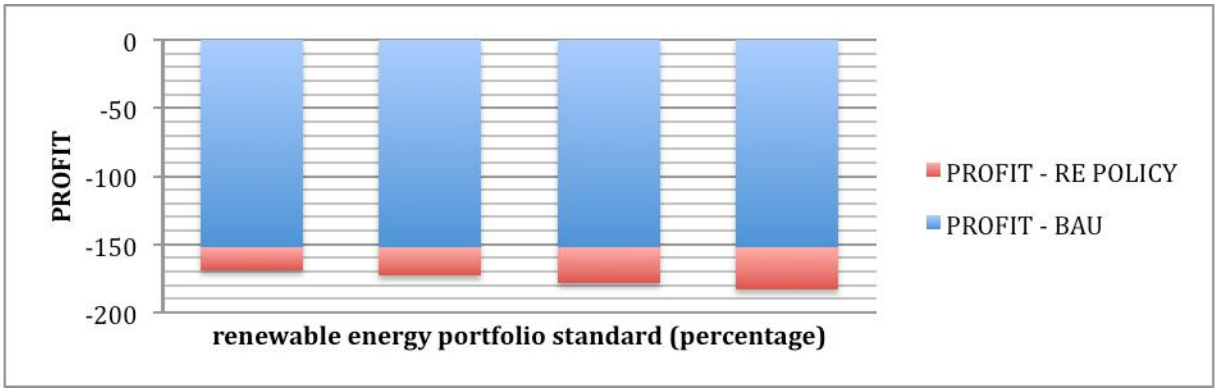

Figure 9: Evolution of the profit under renewable energy portfolio standard policies

Figure 10 summarizes the evolution of profits under the three different policy options. We represent the profits from business-as-usual to renewable energy policy scenarios. One can remark that, as evidenced above, the highest profit is realized under the business-as-usual framework of the coal sector, therefore when the carbon tax is not yet introduced (A). But once a carbon tax is introduced, profits decrease over time until the point (C), up to the point where the firm decides to leave the market while it could not expected a positive profit corresponding to its production (the shut-down point). Therefore the only sample where positive profits could be realized is between [A – B] corresponding to all tax values lower than $\theta_c^* = 0{,}3$. Between [0, 3 ; 2, 5] the firm remains in the market but makes negative profit until (C), when it leaves the market. Such behavior could be explained by the relative value of the tax policy, which could motivate the firm to wait by making a tradeoff between an increase of tax values and a fall of coal-based electricity provided. The point (G) shows the value from which profit of the enterprise, with a renewable energy price-based subsidy, becomes positive and therefore it becomes efficient to diversify the electricity supply structure. In (E), when there are not policies the profit remains negative, preventing a promotion of renewable energy. The firm diversifies its electric supply structure by introducing renewable energy once the value of the subvention is higher than 1, 06, therefore in the sample $\left[1{,}06; +\infty\right]$. The points (F) and (I) show values of (x), under which no clean electricity is provided. Like in the policy of carbon tax, the firm leaves the market (shut – down point) in (F) because it can't provide electricity anymore. Therefore the firm won't diversify its supply structure during the renewable energy portfolio standard while it earns negative profits from the beginning, contrary to the tax policy where it earns positive profits between (A) and (B). Table 4 provides tax and subsidy values ensuring a positive profit.

Table 4: threshold values of renewable energy policies

$\theta_c / \Pi^c / \theta_c \geq 0$	$\theta_c \leq 0{,}3$ (\$/kg CO2)
$s / \left(\Pi^R / s + \Pi^c / s \right) \geq 0$	$s \geq 1{,}06$ (\$/Kwh)
$x / \left(\Pi^R / RPS + \Pi^c / RPS \right) \geq 0$	Impossible

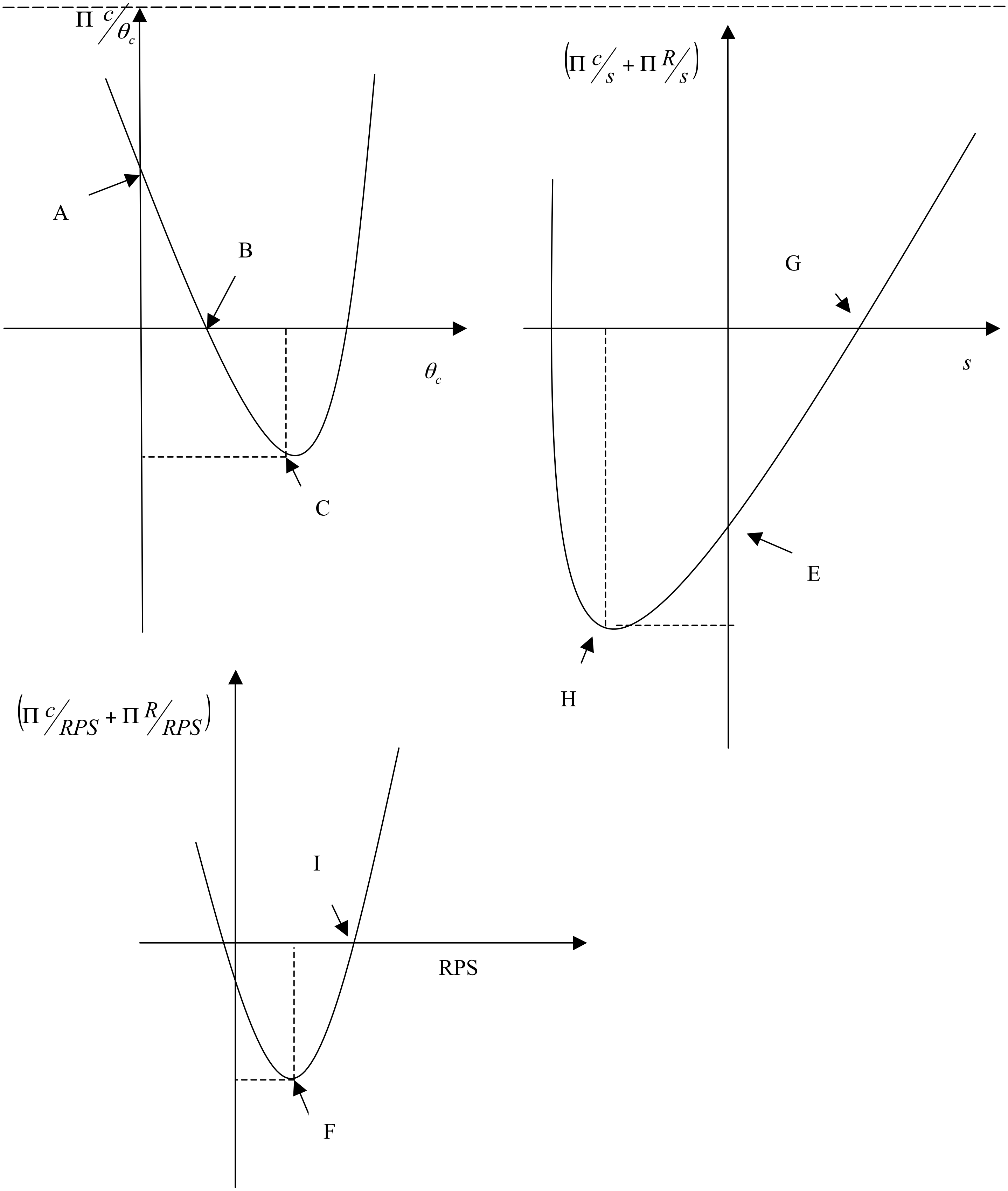

Figure 10: Evolutions of profits under different policy options

Figure 11 shows the evolution of the economic surplus according to the evolution of carbon prices. It shows that an increase of carbon prices increases economic surplus. Moreover we determine values of emission prices ensuring a positive economic surplus. Figure 12 shows that with the carbon tax, social welfare becomes positive if emission prices are higher than $Min\psi^{\theta_c}/_{\Delta W \succ 0} = 5{,}45\$ / tCO2$. In the case of price subsidies, economic surplus becomes positive once the emission price becomes higher than $Min\psi^{s}/_{\Delta W \succ 0} = 0{,}7\$ / tCO2$. To determine the economic surplus we combine equations (15) and (16) and assume that taxes collected are latter distributed in form of subsidies, therefore a so-called "white operation". Such an assumption has important impacts in terms of public policies. First, it allows a neutrality of public resources while price-based subsidies are directly acquitted by polluters. Second this assumption allows also firms to make a tradeoff between tax paid and subsidies received while in this paper a transition towards sustainable energy productions is carried out by firms producing at the same time electricity from coal and renewable energy sources. Finally this assumption allows us to challenge the suitability of our model while we found a $\beta = 1 - \frac{\theta_c}{s} = 0{,}28$ close to our original assumption about $\hat{\beta}\%$, which reflect the forecast of DME in terms of renewable energy promotion in years 2025[46] .

[46] Indeed the Department of Mineral Energy (2008) targeted a percentage of 25% of electricity structure being generated from renewable resources by 2025.

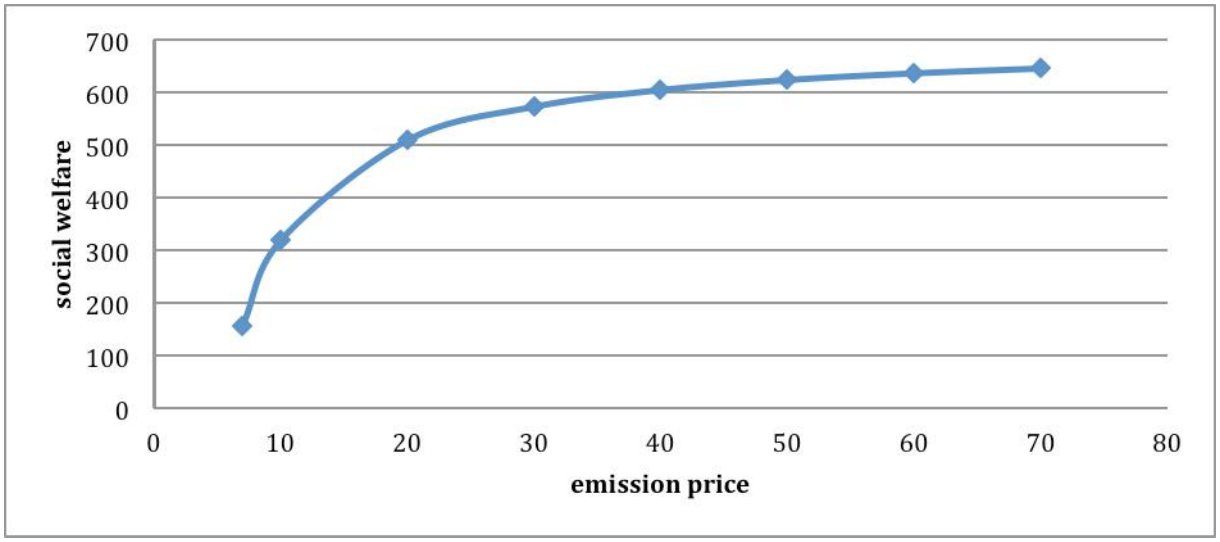

Figure 11: evolution of economic surplus according to emission prices

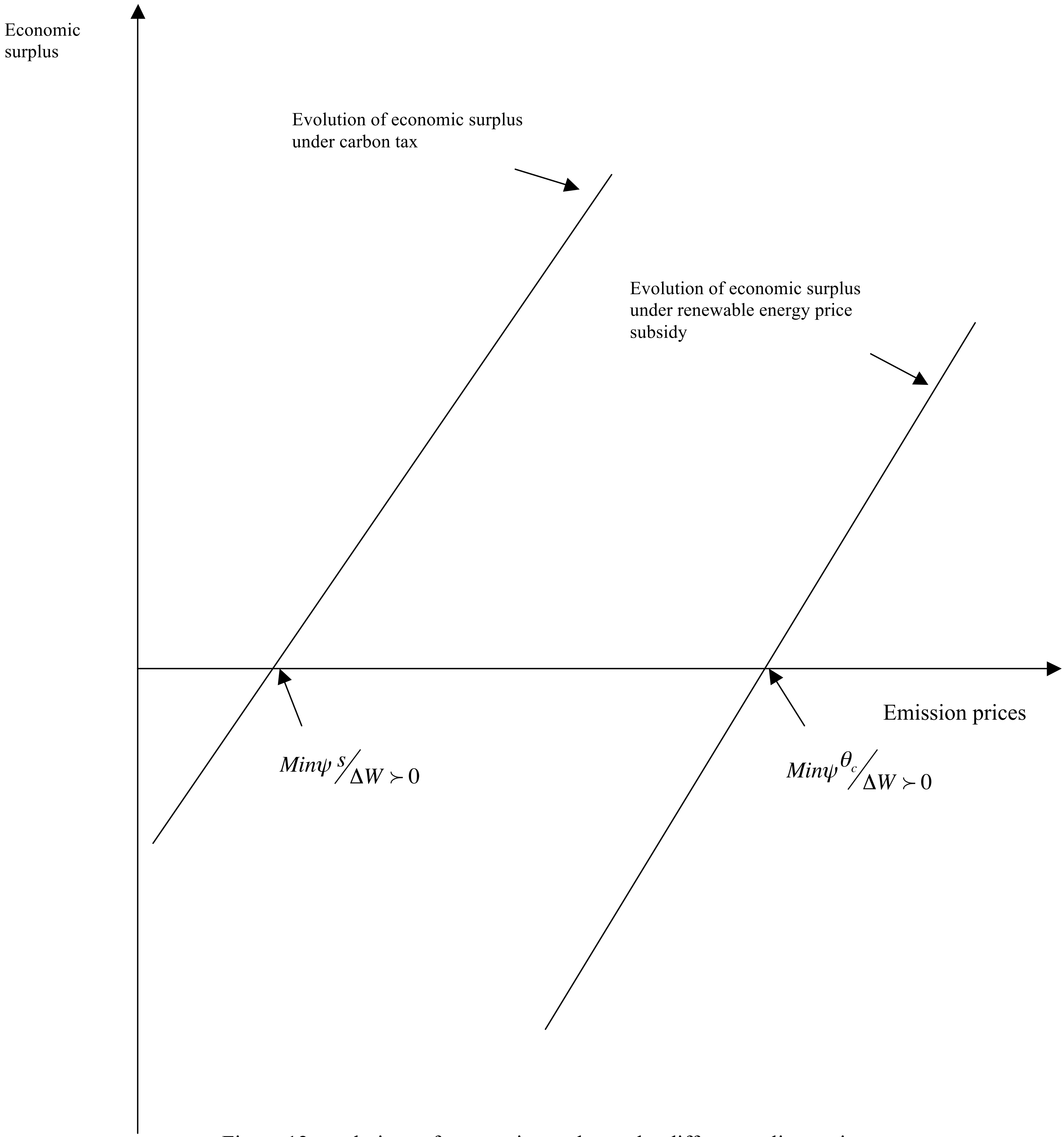

Figure 12: evolutions of economic surplus under different policy options

6.6. a: Policy implications

Our results show importance to put in place right public policies in order to promote a transition towards a more sustainable energy production. We show that putting tax policies in the fossil fuel sector decreases profits of the firm up to the point where its production is equal to 22, 73 MW. An increase of tax policies deepens the decrease of production until its negative value, therefore until the firm's shut-down point. When subsidy policies are carried out the firm diversifies its production by an increase of a share of renewable energy as long as the value of the subsidy remains at least higher than 1,06 $/kwh. Moreover we provide the minimum value of emission prices over which economic surplus becomes positive namely 5,45 $/ t CO2 and 0, 7 $/ t CO2 for respectively fossil fuel and renewable sectors. Therefore, ours findings indicate that emission prices need to guarantee a positive economic surplus in the fossil fuel sector is much more higher compared to those need under the renewable energy sector. This is understandable because emission generated in the fossil fuel scenario is higher than emission generated when renewable energies are considered. In terms of energy policy our results can at least have two implications. (1) Our results allow simulating how a representative firm reacts according to an introduction of different public policies in order to promote a deployment of renewable technology in South Africa while integrating a coal-based comparative advantage of the country. We have shown that an introduction of tax and subsidy policies allows an increase of renewable energy although tax represents the most cost-competitive option. Moreover subsidies ensure more dynamism in the energy market while they continuously increase payoffs yield during the transition towards a more sustainable energy production. The second implication of ours findings (2) is related to impacts of such incentive mechanisms on both economic surplus and environmental emissions. We have shown that in terms of emission levels, carbon taxes provide better response to diminish environmental emission. While an increase of the tax rate decreases coal-based electricity produced, it reduces, all things being equal, associate emissions. Before the break-even point an increase of tax policies decreases emissions generated through a decrease of the energy provided and the end-of-pipe costs involved in the production process. Between the break-even and the shut-down points emissions generated are reduced until the shut-down point where the firm is no more present in the market. Moreover our findings enable to assess emission price ensuring a positive social welfare for South Africa while integrating resource endowment, technological capacities and incentive mechanisms. We have seen that a transition towards a sustainable energy paradigm requires to mobilizing policy options. But ours results have shown that each option has advantages and drawbacks, it depends on what are the targeted objectives. If the objective is purely to increase the share of renewable energy in the electric supply portfolio, from the investor perspective carbon tax and renewable energy price-based subsidies give better options. Whereas if the objective is to reduce the emission level, then carbon tax becomes the optimal instrument. Our results show that renewable energy portfolio standard does not provide good opportunities to promote a sustainable energy transition in South Africa while it yields a negative outcome from the investor prospective. However beyond efficiency effects, impacts of distributional effects are also important when designing optimal policy instruments in order to promote a deployment of renewable technologies. In our case study we show threshold effects of emission prices guaranteeing a positive economic surplus in South Africa. The evolution of emission prices is important because we have assumed a fix percentage of energy generated from coal resources. Therefore in our model the weight of environmental damages has a deep impact on the evolution of the outcomes while they capture the willingness of the country to provide a right price signal through an internalization of environmental costs.

6.7: Conclusion

The objective of this paper has been to assess impacts of an array of policy options for a deployment of renewable technologies in South Africa. Based on the current debate of renewable energy promotion in South Africa we selected three different policy options namely a policy of a carbon tax, a renewable energy price subsidy and the renewable energy portfolio standard. The policy of a carbon tax charges a firm to a payment of a tax rate according to an increase of its pollutant level. In our model these pollutant levels are generated in using coal resources to provide electricity. The renewable energy price subsidy assumes a supplement of a subsidy rate added to the renewable energy price in order to increase the payoff of energy producers. Finally the renewable energy portfolio standard fixes a percentage of electricity to be generated from renewable energy resources. These policy options allow us, on the one hand, to differentiate between “state” and “market” drivers of renewable energy promotion in developing nations. On the other hand, these policies provide South Africa an overview of different options to promote a transition towards sustainable energy solutions. Moreover we also introduce the well endowment of coal resources of the country in order to take into account the comparative advantage of South Africa. Therefore our strategy is to simulate an energy transition through an evolutionary process.

We used optimization techniques through linear programming algorithms in order to analyze the evolution of profits under different policy options. In doing so we differentiate between fossil fuel and renewable energy sectors. In the fossil fuel sector we assume that electricity is entirely generated in using exclusively coal resources whereas in the renewable energy sector coal and renewable resources could be mixed. Evolutions of profits are analyzed under business-as-usual and renewable energy policy scenarios. Under the business-as-usual scenario, we assume that there are not policy options raised in order to promote a deployment of clean technologies contrary to the renewable energy scenario where such policies are raised. The results of our analysis show that once integrating the coal-based resource endowment into the simulation process, only carbon tax and renewable energy price-based subsidy policies promote a transition towards a sustainable energy production, therefore reduce the associated environmental damage. Moreover we show also that in the case of carbon tax and renewable price subsidies, emission prices should be adequately scrutinized in order to guarantee a global surplus.

However though this analysis could allow to lay foundations about strategies allowing a deployment of renewable technologies its must be highlighted that our results are based on assumptions made. Therefore with different assumptions on, for example, technological costs or parameters one could expect different results. But the objective of this paper was rather to provide an overview of policy options strengthening decision-makings in energy sector. In this framework, our analysis gives energy policy-makers in South Africa a broad understanding on eventual impacts of different policy options.

Chapitre 7: Conclusion générale

7 : Conclusion

Fournir de l'énergie propre aux populations des pays en développement (PED) tout en respectant la qualité environnementale peut, dans une large mesure, être atteint lorsque de bonnes politiques incitatives sont mises en place de manière progressive. La thèse a contribué à cette réflexion en proposant d'appréhender la transition énergétique dans les PED sous une approche mixte. L'approche mixte consiste d'une part à favoriser le développement de l'électrification décentralisée, permettant aux zones rurales éloignées d'accroitre leurs niveaux d'accès aux services énergétiques. Dans un second temps, la transition énergétique consistera également à renforcer la diversité de l'offre énergétique à travers l'introduction des technologies propres dans la structure de production centralisée.

La mise en place des politiques publiques incitatives visant à promouvoir l'émergence des technologies propres devrait se faire de manière progressive en prenant en compte certains facteurs internes. Ces facteurs internes peuvent être la dotation des facteurs naturels (combustible fossiles, ressources renouvelables), économiques (niveaux d'inégalité, contrainte budgétaire des pouvoirs publics, performances économiques), physiques (caractéristiques géographiques des populations). Dans ce cadre, une démarche assez transversale mais également pointillée est nécessaire pour promouvoir la transition énergétique dans les PED. Notre travail empirique s'est basé sur deux pays en développement de caractéristiques assez hétérogènes : l'Afrique du Sud et le Sénégal. Cependant, bien que ces deux pays se différencient en termes du nombre de population, de système politique et de structure économique, ils présentent certaines similarités. Ils font faces à des conditions économiques défavorables, une différence d'accès de services énergétiques entre les zones urbaines et rurales et une dépendance aux combustibles fossiles pour la production d'électricité. Dans ce cadre, appréhender la transition énergétique dans ces deux pays reviendrait à investiguer les mêmes points dans le secteur énergétique.

Nous avons mené différentes études empiriques basées sur les modèles de simulations pour analyser l'apport des énergies renouvelables à la transition énergétique. Pour analyser le rôle des technologies renouvelables sur la transition énergétique nous nous sommes focalisés sur quatre questions de recherches. La première question (Q1) s'est focalisée sur les déterminants de la transition énergétique dans les PED et les structures de gouvernance pouvant faciliter leur diffusion. La seconde question (Q2) analyse comment les technologies propres peuvent favoriser la décentralisation énergétique dans les zones éloignées au Sénégal (Q2a) et quels sont les impacts économiques, environnementaux et sociaux des politiques incitatives permettant de favoriser leur adoption (Q2b). La troisième question (Q3) de recherche s'est focalisée sur le secteur électrique en analysant la possibilité pour les technologies propres de contribuer à la diversification de l'offre énergétique au Sénégal et en Afrique du Sud. La dernière question (Q4) de la thèse analyse les conséquences économiques, environnementales et sociales de la mise en place des politiques publiques visant à promouvoir le déploiement des technologies propres.

7. 1: Principaux résultats

Le premier chapitre de la thèse analyse les déterminants de la transition énergétique dans les PED (Q1). Nous avons identifié les déterminants coûts, de marché et institutionnels pouvant favoriser le développement des énergies renouvelables dans les PED. Dans ce chapitre, les déterminants sont assimilés aux facteurs pouvant contraindre la diffusion des technologies propres. Dans un second temps, afin de contourner ces contraintes, nous avons proposé une approche de gouvernance permettant de diffuser stratégiquement les technologies propres dans les PED. Nous avons préconisé une approche séquentielle basée sur la combinaison du « *State Ownership Supply Approach* » du « *Public-Private Partnership* » et du « *Multi-Level Stakeholders Governance* ».

Le second chapitre de la thèse analyse comment les technologies propres peuvent permettre d'accroitre l'accès aux services énergétiques dans les zones rurales (Q2a). Notre analyse empirique s'est focalisé sur trois zones rurales au Sénégal à travers la mise en place du Projet Microgrids. Le projet Microgrids est un projet financé par la commission européenne et qui vise à encourager la transition énergétique dans les zones éloignées des PED. Notre méthodologie de travail s'est basée sur l'analyse du cycle de vie des technologies renouvelables. Nos résultats ont montré la compétitivité coût des technologies propres comparé aux technologies polluantes comme le diesel.

Le troisième chapitre de la thèse simule la mise en place des mécanismes incitatifs visant à promouvoir le développement des technologies propres à travers des processus décentralisés (Q2b). Nous avons privilégié une approche tarifaire en simulant l'impact d'une tarification au coût marginal, au coût moyen et du « *Renewable Energy Premium Tariff* » sur la promotion des énergies propres. Le « *Renewable Energy Premium Tariff* » est une politique tarifaire incitative prônée par la Commission Européenne visant à accroitre l'adoption des technologies propres dans les zones rurales éloignées. Nos résultats ont montré l'impact positif de la tarification au cout moyen et du « *Renewable Energy Premium Tariff* » sur l'adoption des technologies propres. Pour la tarification au coût marginal, nos résultats ont montré un impact négatif. Par ailleurs, en analysant l'impact des politiques tarifaires sur le bien être social, nous montrons que la mise en place du « *Renewable Energy Premium Tariff* » devrait être faite en prenant en compte son potentiel impact sur le bien-être. Autrement dit, sa mise en place doit être bornée par un seuil à partir du quel son augmentation causerait des pertes au niveau du bien-être global. Ce chapitre a également insisté sur l'impact de la fiabilité des institutions sur la performance de telles politiques tarifaires.

Le chapitre 4 se focalise particulièrement sur le secteur électrique de l'Afrique du Sud et du Sénégal. Nous avons analysé l'apport des technologies propres à promouvoir la diversification de l'architecture de l'offre électrique (Q3) des deux pays. Nos résultats ont montré la compétitivité des technologies propres en Afrique du Sud. Pour le cas du Sénégal, nos résultats ont montré que les technologies polluantes sont les plus rentables économiquement pour produire de l'électricité. Deux effets justifient ces résultats. Dans un premier temps, la compétitivité des technologies propres sur la mixité énergétique en Afrique du Sud est facilitée par les effets d'échelles. La production d'énergie en Afrique du Sud est 80 fois plus importante que celle du Sénégal. Dans un second temps, ce résultat est également justifié par les effets d'apprentissages. L'Afrique du Sud bénéficie d'un effet d'apprentissage beaucoup plus important que le Sénégal, à travers différentes expériences d'implantation de technologies propres. Finalement, la diversité des ressources renouvelables (excepté l'hydroélectricité) est également beaucoup plus accentuée en Afrique du Sud qu'au Sénégal.

Le chapitre 6 de la thèse analyse les conséquences économiques, environnementales et sociales de la mise en place des politiques publiques visant à promouvoir le déploiement des technologies propres en Afrique du Sud. Nous avons simulé trois différentes politiques de promotion des technologies propres en Afrique du Sud : la taxe carbone, une subvention tarifaire de l'énergie propre et le « *Renewable Energy Portfolio Standard* ». En prenant en compte les dotations en combustible fossiles, nos résultats ont montré qu'une politique de taxe carbone et de subvention aux prix des énergies renouvelables favoriserait le déploiement des technologies propres. Nos résultats ont également fourni les seuils de prix d'émission, de niveau de taxe, du taux de subvention garantissant des résultats satisfaisants en termes de profits et de bien-être social.

7.2 : Implications en termes de politiques énergétiques

Nos résultats ont montré l'apport des technologies propres sur la transition énergétique en Afrique du Sud et au Sénégal. En termes de politique énergétique, nos résultats ont principalement deux implications. Dans un premier temps, nos résultats ont soulevé l'importance d'une structure institutionnelle performante et fiable pour la conduite des politiques de promotion des énergies propres. La fiabilité institutionnelle permet de mener à bien les politiques de gouvernance encourageant la diffusion des technologies propres. Par exemple, elle permet d'assurer une planification et une coordination optimale des différentes actions de mise en place d'une stratégie de gouvernance. Cette fiabilité peut à la fois combiner le professionnalisme de la mise en place des politiques en anticipant les différentes alternatives (difficultés) possibles des différentes stratégies. L'institution dans sa dimension de « rules of the game », est le garant de la mise en place des mesures de promotion des énergies propres dans les PED.

Dans un second temps, nos résultats permettent également d'effectuer un arbitrage entre différentes politiques incitatives de promotion des énergies renouvelables pour les PED. Nous avons remarqué durant tout le long de la thèse qu'une attention particulière doit être prêtée aux impacts redistribués des politiques incitatives. Par exemple, dans l'ensemble des politiques incitatives simulées dans cette thèse (renewable energy premium tariff, la taxe carbone, une subvention tarifaire de l'énergie propre et le renewable energy portfolio standard) une attention doit être prêtée à leurs impacts sur le bien-être global.

7. 3: Apport personnel de la thèse

L'apport personnel de la thèse peut également se situer à deux niveaux. Dans un premier temps, cette thèse a amené une nouvelle touche sur la réflexion autour de la transition énergétique dans les PED en proposant une approche combinée entre processus décentralisé et centralisé. Dans un second temps, cette thèse a proposé une démarche empirique, basée sur des outils de simulations, permettant d'analyser la transition énergétique dans les pays en développement. Dans ce cadre, elle peut servir d'outils pratiques pour les « energy policy-makers » en Afrique du Sud et au

Sénégal lors de la mise en place des politiques publiques visant à promouvoir la diffusion des technologies propres. Au delà de ces deux pays, cette thèse pourrait servir « d'input » pour certains pays en développement de caractéristiques identiques à ceux traités içi lors de la mise en place des politiques de promotion des énergies renouvelables.

7.4: Limites et pistes de recherche

Comme tout travail scientifique, cette thèse se trouve également confrontée à certaines limites. Certains points, bien qu'importants, n'ont pas été abordés. Deux points nous semblent être très importants pour la suite des recherches futures. Dans un premier temps, la nature de la structure des marchés électriques peut avoir des impacts non négligeables sur les choix des politiques incitatives de promotion des énergies renouvelables. Les politiques incitatives ont des impacts différents selon qu'on suppose qu'on est dans une situation de concurrence pure et parfaite et selon qu'on est dans une situation de monopole.

Dans un second temps, il serait également intéressant d'introduire l'incertitude dans l'analyse de la transition vers les technologies propres. En effet, puisque la transition requiert la combinaison des facteurs économiques, technologiques et institutionnels, la prise en compte des incertitudes donnerait une approche plus réaliste de la situation. L'incertitude dans le domaine énergétique peut avoir des fondements économiques, technologiques et institutionnels.

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Annexes
Data used to calibrate the model in chapter 5

PowerPlan data sheet

Senegal 2006 BAU

Starting Values (Data from Lawrence Berckeley Lab, China energy databook)

2006	Starting year
24	Simulation length
1	Periodlength
400	SMD in year 0 was 387
1,3	Economic optimal reserve factor percentage
5,806	GDP (constant 1995 Yuan) per capita
10000000	Population in year 0
0	Chronological calculations (1) or not (0)

System Values

0,0612	Interest
0	ShortRun PriceElasticity
0	LongRun PriceElasticity
0,05	PeakLoad Fraction
2000	Peak load hours
6000	Middle load hours
50	Available capital percentage
50	Electricity Capital Share percentage
0,12	Fraction of ash retained in coal-fired boiler (bottom-ash)
0,998	Fraction of particulate retained by electro-static filters
2,6	Flue gas desulphurisation waste in ton per ton of SO2
0,05	Fraction of sulphur retained in ash
0,0000385	High level nuclear waste in m^3 per MWhe
0,0000154	Medium and low level nuclear waste in m^3 per MWhe
0,5	High level decommissioning nuclear waste in m^3 per MW
0,5	Medium and low level nuclear waste in m^3 per MW
0,04	T&D losses

4	T&D Construction time
60000	T&D Capital invest Monetary units / MWe installed
0	(* Available Cap. Multiplier works (= 1) or not (= 0) *)
0,8	(* Available Cap. Multplier constant A (ACM := Const_A + Const_B * Exp
0,2	(* Available Cap. Multplier constant B *)
0,06	(* Own electricity use as fraction of total production *)

Miscellaneous variables

2	The consequences of Nuclear accidents are accounted with (0=no, only me
US$	Currency String

Maximum of 25 types of Power plants. Name length max. 15 characters

Hydro

Coal

CC

Steam

Diesel

Gasturbine

"Several time-series, number of data per series depends on the ""simulation length"" in the sheet: ""General"" (Length+1)"

The first two series (GDP and population Growth) are essentials. The third can be the SMD Growth (%) or the GDP-electricity elasticity

In the latter case the SMD growth will be calculated from GDP growth, Population growth and the GDP-electricity elasticity

GDP Growth per capita (%)

2,3	4,7	2,5	1,5	3,4	4,3	4,7	4,6	4,5	4,8	4,9	5	5,01
	4,54	4,34	5,13	5,15	5,15	5,19	5,2	5,18	5,14	5,12	5,15	5,3
	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3
	5,3	5,3	5,3									

Population Growth (%)

2,5 2,5 2,5 2,4 2,4 2,4 2,2 2,2 2,2 2,2 2,2 2,2 2,2
2,2 2,2 2,2 2 2 2 2 2 2 2 1,9 1,9
1,9 1,9 1,9 1,9 1,9 1,9 1,9 1,9 1,9 1,9 1,9 1,9
1,9 1,9 1,9

Not used "the text in the first column of this row is essential. It ought to be: ""GDP Electr Elasticity"""

SMD Growth (%) "the text in the first column of this row is essential. It ought to be: ""SMD Growth (%)"" or ""GDP Electr Elasticity"""

5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 1,5
1,5 1,5 1,5 1,5 1,5 1,5 1,5 1,5 1,5 1,5 1,5 1,5
1,5 1,5

CO2 Tax euro/ton

0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0

T&D Losses

0,28	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25
	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25
2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5

Fuel parameters

Coal	Lignite	Peat	MSW	Bio-fuel		Gas	Oil	FreeFuel	Uranium
0,1	0,1	0,1	0,05	0,05	1	1	0,1	0,05	Parity with oil
47	25	25	10	600	41	111	47	250	Initial price in basic year
93,8	94	94	74	0	56,1	74	115	0	CO2 emission

Fuels present, the oil price path always ought to be present

"1 means present; 0 means not present in this spreadsheet"

oil coal natural gas uranium Coal gas Coke MSW bio-fuel LPG Hydrogen

1 1 1 0 0 0 0 0 0 0

"The first value just below the fuel type (row 8) is the year the price path starts; Row 9: number of years present in price path"

Oil price path Coal price path Natural gas price path Uranium gas price path Coal gas price path MSW price path Bio-fuel price path Hydrogen price path LPG price path

2000	2000	2000
33	33	33
298,5	75,0	225,0
309,0	82,5	234,0
313,5	82,5	237,0
318,0	85,5	240,0
218	60	165
221	60	167
224	62	170
227	63	172
230	63	174
233	64	176
235	64	179
239	65	181
241	65	183
245	65	185
247	65	188
250	65	190
253	65	192

256	66	195
259	66	197
262	66	199
265	66	201
268	67	204
271	67	206
274	67	208
277	67	210
280	67	213
283	67	215
286	67	217
289	68	220
292	68	222
295	68	224
298	68	226

"Fuel values; 4 fuel grades per fuel type"

Fuel-Grade Price H.Rate Frac. Sulphur% Ash cont. ERE

Coal-RG 1 25 1 1,1 20 1,152 H.Rate Heat Rate (GJ/kg): Coal, Lignite, Peat, MSW, Biofuel, Oil, Uranium (m3): Natural gas, Free fuel)

Coal-A1,05 25 0 1 20 1,152 Frac. Fuel Frac.

Coal-B1,1 25 0 0,5 15 1,152 Sulpur Sulphur Content (%)

Coal-C1,15 25 0 0,3 10 1,152 Asc cont. Ash Content

Lignite-RG 1 25 1 3 10 1,152 HR: HeatRate

Lignite-A	1,05	25	0	3	10	1,152	ERE	Energy Requirements for Energy
Lignite-B	0,95	25	0	3	12	1,152		
Lignite-C	1	25	0	3	10	1,152		
Peat-RG	1	18	1	3	10	1,152		
Peat-A	1,05	18	0	3	10	1,152		
Peat-B	0,95	18	0	3	12	1,152		
Peat-C	1	18	0	3	10	1,152		
MSW-RG	1	8,5	1	0,096	25	6,6		
MSW-A	1,05	8,5	0	0,09	23	6,6		
MSW-B	1,1	8,5	0	0,085	20	6,6		
MSW-C	1,2	8,5	0	0,08	18	6,6		
Biofuel-RG	1	15	1	1,35	5	0,03		
Biofuel-A	1,1	15	0	1,3	4,5	0,03		
Biofuel-B	1,2	15	0	1,2	4	0,03		
Biofuel-C	1,3	15	0	1,1	3,5	0,03		
Gas-RG	1	31,65	0,9	0	0	1,008		
Gas-A	1,1	42	0	0	0	1,006		
Gas-B	1,2	31,65	0	0	0	1,005		
Gas-C	1,3	31,65	0,1	0	0	1,008		
Oil-RG	1	41,86	1	1,35	0	1,124		
Oil-A	1,1	41,86	0	1,3	0	1,124		
Oil-B	1,2	41,86	0	1,25	0	1,124		
Oil-C	1,3	41,86	0	1,2	0	1,124		
Hydrogen-RG	1	5	1	0,15	0	1,008	HR	: MJ/m3

Hydrogen-A	1,2	5	0	0,7	0	1,008
Hydrogen-B	1,4	5	0	0,6	0	1,008
Hydrogen-C	1,5	5	0	0,5	0	1,008
Uranium-RG	1	145	1	0	0	1,4
Uranium-A	1	145	0	0	0	1,4
Uranium-B	1	145	0	0	0	1,4
Uranium-C	1	145	0	0	0	1,4

Load Duration Curve

10	number of points in the LDC	25	10
1		1	
0,95		0,88	
0,87		0,76	
0,78		0,66	
0,71		0,58	
0,67		0,51	
0,63		0,45	
0,6		0,4	
0,56		0,35	
0,52		0,3	
0,46		0,220	

Inputs to build a year pattern on a hourly basis

Weekday

300000

0,58	0,5	0,48	0,48	0,5	0,55	0,65	0,75	0,85	0,95	1	1	1
	0,95	0,96	0,96	0,94	0,93	0,92	0,9	0,83	0,8	0,7	0,65	

Saturday

0,63	0,6	0,5	0,5	0,5	0,5	0,6	0,7	0,8	0,9	0,95	0,95	0,95
	0,9	0,9	0,9	0,85	0,8	0,75	0,75	0,75	0,73	0,72	0,68	

Sunday

0,6	0,52	0,49	0,47	0,46	0,46	0,5	0,6	0,7	0,8	0,85	0,85	0,85
	0,8	0,8	0,8	0,75	0,7	0,65	0,65	0,65	0,65	0,63	0,62	

Load	Spring	Summer	Autumn	Winter
PeakLoad	0,88	0,87	0,86	1
BaseLoad	0,83	0,8	0,82	1

Power plants (retrofitting a few plants to > 2015 & > 2030)

Name Reference list numberYear in operation Year out operation Capacity (MW) Fuel type Load type (B=base load, M=middle load, P=peak load) Efficiency NOx emission (g/GJ) SO2 emission reduction (fraction) CO2 storage Capacity costs Assigned energy: only to fill in when fuel type is (pump)storage Ps Domestic production company, or Foreign production company when fuel type is Import (I) see sheet Imports Location/Name

Diesel 1 1990 2030 4 O M 0,3 37 0 0 100
Bel-air C I year out ??

Steam 1 1953 1993 0 O P 0,3 37 0 0 100
Bel-air C II year out ??

Steam 1 1955 1995 0 O P 0,3 37 0 0 100
Bel-air C II year out ??

Steam 1 1959 1999 7 O P 0,3 37 0 0 100
Bel-air C II year out ??

Steam 1 1961 2001 7 O P 0,3 37 0 0 100
Bel-air C II year out ??

Gasturbine 1 1999 2039 30 G M 0,41 28 0 0 100
Bel-air C II snap ik niet helemaal (zie www.senelec.sn)

Diesel 1 2006 2046 65,8 O M 0,3 37 0 0 100
Bel-air C6 65.8 na 2006?

Steam 1 1966 2006 22 O M 0,3 37 0 0 100
Cap des biches C III vapeur year out ??

Steam 1 1975 2015 18 O M 0,3 37 0 0 100
Cap des biches C III vapeur year out ??

Steam 1 1978 2018 22 O M 0,3 37 0 0 100
Cap des biches C III vapeur year out ??

Gasturbine 1 1984 2024 20 G P 0,38 28 0 0 100
Cap des biches C III TAG ?? 1971 missing ??

Gasturbine 1 1995 2035 0 G P 0,4 28 0 0 100
Cap des biches C III TAG ??

Diesel 1 1990 2030 18 O M 0,3 37 0 0 100
Cap des biches C IV

Diesel 1 1990 2030 18 O M 0,3 37 0 0 100
Cap des biches C IV

Diesel 1 1997 2037 19 O M 0,3 37 0 0 100
Cap des biches C IV

Diesel	1	2003	2043	15	O	M	0,3	37	0	0	100	
	Cap des biches			C IV		year out ??						
Diesel	1	2003	2043	15	O	M	0,3	37	0	0	100	
	Cap des biches			C IV		year out ??						
Diesel	1	1979	2019	5	O	M	0,3	37	0	0	100	
	Sites Regionaux			St-Louis			year out ??					
Diesel	1	1982	2022	5	O	M	0,3	37	0	0	100	
	Sites Regionaux			Kahone			year out ??					
Diesel	1	1988	2028	5	O	M	0,3	37	0	0	100	
	Sites Regionaux			Kahone			year out ??					
Diesel	1	1984	2024	4	O	M	0,3	37	0	0	100	
	Sites Regionaux			Boutoute			year out ??					
Diesel	1	1986	2026	4	O	M	0,3	37	0	0	100	
	Sites Regionaux			Boutoute			year out ??					
Diesel	1	1999	2039	3,2	O	M	0,3	37	0	0	100	
	Sites Regionaux			Boutoute			year out ??					
Diesel	1	1999	2039	3,2	O	M	0,3	37	0	0	100	
	Sites Regionaux			Boutoute			year out ??					
Diesel	1	2006	2046	5	O	M	0,3	37	0	0	100	
	Sites Regionaux			Boutoute								
Diesel	1	1999	2039	4,6	O	M	0,3	37	0	0	100	
	Sites Regionaux			Tambacounda			left out					
Diesel	1	1999	2039	4	O	M	0,3	37	0	0	100	
	Sites Regionaux			Kolda								
CC	1	1999	2039	50	O	B	0,4	28	0	0	100	
	Prive	GTI		50 MW ??								
Hydro	1	2002	2102	60	P	B				0	119	280
	Prive	Manantali										
Diesel	1	2007	2047	67,5	O	M	0,3	37	0	0	100	
	Prive	Kounoune 1			3,84							
Diesel	1	2005	2045	40,8	O	M	0,3	37	0	0	100	
	Prive	Aggreko										

Coal	1	2010	2050	165	C	B	0,38	28	0	0	139
Diesel	1	2006	2046	15	O	M	0,35	37	0	0	90
Diesel	1	2006	2046	18	O	M	0,35	37	0	0	90
Steam	1	2007	2047	19	O	M	0,35	37	0	0	90
Gasturbine	1	2008	2048	20	G	P	0,35	28	0	0	90
Diesel	1	2009	2049	18	O	M	0,35	37	0	0	90
Diesel	1	2010	2050	20	O	M	0,35	37	0	0	90
Steam	1	2011	2051	20	O	M	0,35	37	0	0	90
Gasturbine	1	2012	2052	18	G	P	0,35	28	0	0	90
Diesel	1	2012	2052	19	O	M	0,35	37	0	0	90
Gasturbine	1	2013	2053	20	G	P	0,35	28	0	0	90
Diesel	1	2013	2053	21	O	M	0,35	37	0	0	90
Diesel	1	2014	2054	25	O	M	0,35	37	0	0	90
Diesel	1	2014	2054	28	O	M	0,35	37	0	0	90
Diesel	1	2015	2055	15	O	M	0,35	37	0	0	90
Diesel	1	2015	2055	15	O	M	0,35	37	0	0	90

Diesel	1	2016	2056	18	O	M	0,35	37	0	0	90
Gasturbine	1	2016	2056	18	G	P	0,35	28	0	0	90
Gasturbine	1	2016	2056	19	G	P	0,35	28	0	0	90

			542,1	512,1		
calc			stat			
			calc	stat		
113,8	Bel-air		113,8			
		Gasturbine		50	50	
167	Cap des biches				167	280,8
		Steam	76	76		
43	Sites Regionaux				49,6	
		Diesel	154,8	167,8		
218,3	Prive		218,3			
			280,8	293,8		

PowerPlan data sheet

South Africa 2006 BAU

Starting Values (Data from Lawrence Berckeley Lab, China energy databook)

2006 Starting year

24 Simulation length

1 Periodlength

400 SMD in year 0 was 387

1,3 Economic optimal reserve factor percentage

10,291 GDP (constant 1995 Yuan) per capita

47000000 Population in year 0

0 Chronological calculations (1) or not (0)

System Values

0,0612 Interest Data from the World Bank, 2006

0 ShortRun PriceElasticity

0 LongRun PriceElasticity

0,05 PeakLoad Fraction

2000 Peak load hours

6000 Middle load hours

50 Available capital percentage

50 Electricity Capital Share percentage

0,12 Fraction of ash retained in coal-fired boiler (bottom-ash)

0,998 Fraction of particulate retained by electro-static filters

2,6 Flue gas desulphurisation waste in ton per ton of SO2

0,05 Fraction of sulphur retained in ash

0,0000385 High level nuclear waste in m^3 per MWhe

0,0000154 Medium and low level nuclear waste in m^3 per MWhe

0,5 High level decommissioning nuclear waste in m^3 per MW

0,5 Medium and low level nuclear waste in m^3 per MW

0,04 T&D losses

4 T&D Construction time

60000 T&D Capital invest Monetary units / MWe installed

0 (* Available Cap. Multiplier works (= 1) or not (= 0) *)

0,8 (* Available Cap. Multplier constant A (ACM := Const_A + Const_B * Exp (Investments/Available Cap.) *)

0,2 (* Available Cap. Multplier constant B *)

0,06 (* Own electricity use as fraction of total production *)

Only one blank row is allowed

Miscellaneous variables

2 The consequences of Nuclear accidents are accounted with (0=no, only messages, 1=yes, 2=no, no messages)

US$ Currency String

Maximum of 25 types of Power plants. Name length max. 15 characters

Hydro

Coal

Nuclear

Gasturbine

"Several time-series, number of data per series depends on the ""simulation length"" in the sheet: ""General"" (Length+1)"

The first two series (GDP and population Growth) are essentials. The third can be the SMD Growth (%) or the GDP-electricity elasticity

In the latter case the SMD growth will be calculated from GDP growth, Population growth and the GDP-electricity elasticity

GDP Growth per capita (%)

2,3 4,7 2,5 1,5 3,4 4,3 4,7 4,6 4,5 4,8 4,9 5 5,01
4,54 4,34 5,13 5,15 5,15 5,19 5,2 5,18 5,14 5,12 5,15 5,3
5,3 5,3 5,3 5,3 5,3 5,3 5,3 5,3 5,3 5,3 5,3 5,3
5,3 5,3 5,3

Population Growth (%)

2,5 2,5 2,5 2,4 2,4 2,4 2,2 2,2 2,2 2,2 2,2 2,2 2,2
2,2 2,2 2,2 2 2 2 2 2 2 2 1,9 1,9
1,9 1,9 1,9 1,9 1,9 1,9 1,9 1,9 1,9 1,9 1,9 1,9
1,9 1,9 1,9

Not used "the text in the first column of this row is essential. It ought to be: ""GDP Electr Elasticity"""

SMD Growth (%) "the text in the first column of this row is essential. It ought to be: ""SMD Growth (%)"" or ""GDP Electr Elasticity"""

5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5
1,5 1,5 1,5 1,5 1,5 1,5 1,5 1,5 1,5 1,5 1,5
1,5

CO2 Tax euro/ton

0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0

T&D Losses

0,28 0,25 0,25 0,25 0,25 0,25 0,25 0,25 0,25 0,25 0,25 0,25 0,25
0,25 0,25 0,25 0,25 0,25 0,25 0,25 0,25 0,25 0,25 0,25 0,25

2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030

2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5
2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5 2,5

5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5

Fuel parameters

Coal LignitePeat MSW Bio-fuel Gas Oil FreeFuel Uranium

0,1 0,1 0,1 0,05 0,05 1 1 0,1 0,05 Parity with oil

47 25 25 10 600 41 111 47 250 Initial price in basic year

93,8 94 94 74 0 56,1 74 115 0 CO2 emission

Fuels present, the oil price path always ought to be present

"1 means present; 0 means not present in this spreadsheet"

oil coal natural gas uranium Coal gas Coke MSW bio-fuel LPG
Hydrogen

1 1 1 0 0 0 0 0 0 0

"The first value just below the fuel type (row 8) is the year the price path starts; Row 9: number of years present in price path"

Oil price path Coal price path Natural gas price pathUranium gas price path Coal gas
price path MSW price path Bio-fuel price path Hydrogen price path LPG price path

2000	2000	2000
33	33	33
298,5	75,0	225,0
309,0	82,5	234,0
313,5	82,5	237,0
318,0	85,5	240,0
218	60	165
221	60	167
224	62	170
227	63	172
230	63	174
233	64	176
235	64	179
239	65	181
241	65	183
245	65	185
247	65	188
250	65	190
253	65	192
256	66	195
259	66	197
262	66	199
265	66	201
268	67	204

271	67	206
274	67	208
277	67	210
280	67	213
283	67	215
286	67	217
289	68	220
292	68	222
295	68	224
298	68	226

"Fuel values; 4 fuel grades per fuel type"

Fuel-Grade	Price	H.Rate	Frac.	Sulphur%	Ash cont.	ERE		
Coal-RG	1	25	1	1,1	20	1,152	H.Rate	Heat Rate (GJ/kg): Coal, Lignite, Peat, MSW, Biofuel, Oil, Uranium (m3): Natural gas, Free fuel)
Coal-A	1,05	25	0	1	20	1,152	Frac.	Fuel Frac.
Coal-B	1,1	25	0	0,5	15	1,152	Sulpur	Sulphur Content (%)
Coal-C	1,15	25	0	0,3	10	1,152	Asc cont.	Ash Content
Lignite-RG	1	25	1	3	10	1,152	HR:	HeatRate
Lignite-A	1,05	25	0	3	10	1,152	ERE	Energy Requirements for Energy
Lignite-B	0,95	25	0	3	12	1,152		
Lignite-C	1	25	0	3	10	1,152		
Peat-RG	1	18	1	3	10	1,152		
Peat-A	1,05	18	0	3	10	1,152		
Peat-B	0,95	18	0	3	12	1,152		

Peat-C	1	18	0	3	10	1,152		
MSW-RG	1	8,5	1	0,096	25	6,6		
MSW-A	1,05	8,5	0	0,09	23	6,6		
MSW-B	1,1	8,5	0	0,085	20	6,6		
MSW-C	1,2	8,5	0	0,08	18	6,6		
Biofuel-RG	1	15	1	1,35	5	0,03		
Biofuel-A	1,1	15	0	1,3	4,5	0,03		
Biofuel-B	1,2	15	0	1,2	4	0,03		
Biofuel-C	1,3	15	0	1,1	3,5	0,03		
Gas-RG	1	31,65	0,9	0	0	1,008		
Gas-A	1,1	42	0	0	0	1,006		
Gas-B	1,2	31,65	0	0	0	1,005		
Gas-C	1,3	31,65	0,1	0	0	1,008		
Oil-RG	1	41,86	1	1,35	0	1,124		
Oil-A	1,1	41,86	0	1,3	0	1,124		
Oil-B	1,2	41,86	0	1,25	0	1,124		
Oil-C	1,3	41,86	0	1,2	0	1,124		
Hydrogen-RG	1	5	1	0,15	0	1,008	HR	: MJ/m3
Hydrogen-A	1,2	5	0	0,7	0	1,008		
Hydrogen-B	1,4	5	0	0,6	0	1,008		
Hydrogen-C	1,5	5	0	0,5	0	1,008		
Uranium-RG	1	145	1	0	0	1,4		
Uranium-A	1	145	0	0	0	1,4		
Uranium-B	1	145	0	0	0	1,4		

Uranium-C	1	145	0	0	0	1,4

Load Duration Curve

10	number of points in the LDC	25	10
1		1	
0,95		0,88	
0,87		0,76	
0,78		0,66	
0,71		0,58	
0,67		0,51	
0,63		0,45	
0,6		0,4	
0,56		0,35	
0,52		0,3	
0,46		0,220	

Inputs to build a year pattern on a hourly basis

Weekday

300000

0,58	0,5	0,48	0,48	0,5	0,55	0,65	0,75	0,85	0,95	1	1	1
	0,95	0,96	0,96	0,94	0,93	0,92	0,9	0,83	0,8	0,7	0,65	

Saturday

0,63	0,6	0,5	0,5	0,5	0,5	0,6	0,7	0,8	0,9	0,95	0,95	0,95
	0,9	0,9	0,9	0,85	0,8	0,75	0,75	0,75	0,73	0,72	0,68	

Sunday

0,6 0,52 0,49 0,47 0,46 0,46 0,5 0,6 0,7 0,8 0,85 0,85 0,85
0,8 0,8 0,8 0,75 0,7 0,65 0,65 0,65 0,65 0,63 0,62

Load Spring Summer Autumn Winter

PeakLoad 0,88 0,87 0,86 1

BaseLoad 0,83 0,8 0,82 1

Power plants reference data

Name EL TL CT Cap (MW) FT NOx SO2 CO2 CapC Eff ExpC
LT PlO ERE Cap Frac Must Run Import Country AsE
CapC (Yuan) old values

Coal 20 25 5 100 C 29 0 0 8190 0,28 0,013 B
0,1 9 0,8 0,5 10500

Gasturbine 20 25 1 25 G 65 0 0 1900 0,25 0,01 P
0,1 6,3 0,8 0 5000

Hydro 30 50 8 50 P 0 0 0 9520 0,08 B
0,05 20 0,8 0 200 15000

Nuclear 20 35 9 500 P 2200 0,006 B
0,15 20 0,8 1 NOX mva=20 DH new

Important!! Distance between both tables must be three rows

Name Max. capacity Nr of states frac. Time frac. Capacity frac. Time frac. Capacity
Pattern Pattr file

Coal -1 2 0,1 0 0,9 1 0
Nuclear -1 2 0,05 0 0,95 1 0

Gasturbine -1 2 0,07 0 0,93 1 0

Hydro -1 2 0 0 1 1 0

Powerplants

name refernce year in Operation year out of operation Capacity (MW) Fuel type
Load type Efficiency Nox emissions SO2 emissions CO2 storage
Capacity cost Assigned energy: only to fill in when fuel type is (pump)storage Ps
domestic location / Name Location /Names

Gasturbine 1 1976 2016 171 G P 0,3 15 0 0 100
Acacia power Station

Coal 1 1966 206 200 C B 0,35 15 0 0 140
Arnot Power Station

Coal 1 2001 2041 980 C B 0,35 15 0 0 140
Arnot power station bis

Coal 1 1990 2030 200 C B 0,33 15 0 0 140
Camden Power station 1

Coal 1 2008 2048 200 C B 0,33 15 0 0 140
camden power station 2

Coal 1 2007 2047 200 C B 0,33 15 0 0 140
Camden power station 3

Coal 1 2007 2047 200 C B 0,33 15 0 0 140
camden power station 4

Coal 1 2007 2047 200 C B 0,33 15 0 0 140
Camden power station 5

Coal 1 2005 2045 200 C B 0,33 15 0 0 140
Camden power station 6

Coal 1 2006 2046 200 C B 0,33 15 0 0 140
camden power station 7

Coal	1	2006	2046	200	C	B	0,33	15	0	0	140		Camden power station 8
Coal	1	1984	2024	600	C	B	0,37	15	0	0	140		Duvha power station 1
Coal	1	1984	2024	600	C	B	0,37	15	0	0	140		Duvha power station 2
Coal	1	1984	2024	600	C	B	0,37	15	0	0	140		Duvha power station 3
Coal	1	1993	2033	600	C	B	0,37	15	0	0	140		Duvha power station 4
Coal	1	1993	2033	600	C	B	0,37	15	0	0	140		Duvha power station 5
Coal	1	2001	2041	600	C	B	0,37	15	0	0	140		Duvha power station 6
Hydro	1	1981	2081	250	P	B			0	0	119	510	Drakensberg pumped storage 1
Hydro	1	1981	2081	250	P	B			0	0	119	510	Drakensberg pumped storage 2
Hydro	1	1981	2081	250	P	B			0	0	119	510	Drakensberg pumped storage 3
Hydro	1	1981	2081	250	P	B			0	0	119	511	Drakensberg pumped storage 4
Hydro	1	1971	2071	90	P	B			0	0	119	222	Gariep hydroelectricity 1
Hydro	1	1971	2071	90	P	B			0	0	119	222	Gariep hydroelectricity 2
Hydro	1	1976	2076	90	P	B			0	0	119	222	Gariep hydroelectricity 3
Hydro	1	1976	2076	90	P	B			0	0	119	223	Gariep hydroelectricity 4
Coal	1	1989	2029	200	C	B	0,33	15	0	0	140		Grootvlei Power station 1

Coal 1 1989 2029 200 C B 0,33 15 0 0 140
Grootvlei power station 2

Coal 1 1989 2029 200 C B 0,33 15 0 0 140
Grootvlei power station 3

Coal 1 1990 2030 200 C B 0,33 15 0 0 140
Grootvlei power station 4

Coal 1 1990 2030 200 C B 0,33 15 0 0 140
Grootvlei power station 5

Coal 1 1990 2030 200 C B 0,33 15 0 0 140
Grootvlei power station 6

Gasturbine 1 1978 2018 200 G P 0,34 15 0 0 100
Hendrina Power station 1

Gasturbine 1 1978 2018 200 G P 0,34 15 0 0 100
Hendrina power station 2

Gasturbine 1 1978 2018 200 G P 0,34 15 0 0 100
Hendrina power station 3

Gasturbine 1 1978 2018 200 G P 0,34 15 0 0 100
hendrina power station 4

Gasturbine 1 1995 2035 200 G P 0,34 15 0 0 100
hendrina power station 5

Gasturbine 1 1995 2035 200 G P 0,34 15 0 0 100
hendrina power station 6

Gasturbine 1 1997 2037 200 G P 0,34 15 0 0 100
hendrina power station 7

Gasturbine 1 1997 2037 200 G P 0,34 15 0 0 100
hendrina power station 8

Gasturbine 1 1997 2037 200 G P 0,34 15 0 0 100
hendrina power station 9

Gasturbine 1 1997 2037 200 G P 0,34 15 0 0 100
hendrina power station 10

Coal 1 1993 2033 686 C B 0,35 15 0 0 140
kendal power station 1

Coal 1 1993 2033 686 C B 0,35 15 0 0 140
kendal power station 2

Coal 1 1993 2033 686 C B 0,35 15 0 0 140
kendal power station 3

Coal 1 1993 2033 686 C B 0,35 15 0 0 140
kendal power station 4

Coal 1 1993 2033 686 C B 0,35 15 0 0 140
kendal power station 5

Coal 1 1993 2033 686 C B 0,35 15 0 0 140
kendal power station 6

Nuclear 1 1976 2016 900 P B 0 0 850
Koeberg nuclear power station 1

Nuclear 1 1985 2025 900 P B 0 0 850
Koeberg nuclear power station 2

Coal 1 1961 2001 100 C P 0,3 15 0 0 140
Komati power station 1

Coal 1 1961 2001 100 C P 0,3 15 0 0 140
komati power station 2

Coal 1 1962 2002 100 C P 0,3 15 0 0 140
komati power station 3

Coal 1 1966 2006 100 C P 0,3 15 0 0 140
komati power station 4

Coal 1 1966 2006 100 C P 0,3 15 0 0 140
komati power station 5

Coal 1 1976 2016 500 C B 0,37 15 0 0 140
Kriel power station 1

Coal 1 1976 2016 500 C B 0,37 15 0 0 140
kriel power station 2

Coal 1 1976 2016 500 C B 0,37 15 0 0 140
kriel power station 3

Coal 1 1976 2016 500 C B 0,37 15 0 0 140
kriel power station 4

Coal	1 kriel power station 5	1976	2016	500	C	B	0,37	15	0	0	140
Coal	1 kriel power station 6	1976	2016	500	C	B	0,37	15	0	0	140
Coal	1 Lethabo power station 1	1990	2030	618	C	B	0,38	15	0	0	140
Coal	1 lethabo power station 2	1990	2030	618	C	B	0,38	15	0	0	140
Coal	1 lethabo power station 3	1990	2030	618	C	B	0,38	15	0	0	140
Coal	1 lethabo power station 4	1990	2030	618	C	B	0,38	15	0	0	140
Coal	1 lethabo power station 5	1990	2030	618	C	B	0,38	15	0	0	100
Coal	1 lethabo power station 6	1990	2030	618	C	B	0,38	15	0	0	140
Coal	1 Majuba power station 1	1996	2036	665	C	B	0,35	15	0	0	140
Coal	1 Majuba power station 2	1996	2036	665	C	B	0,35	15	0	0	140
Coal	1 Majuba power station 3	1996	2036	665	C	B	0,35	15	0	0	140
Coal	1 Matimba power station 1	1987	2027	665	C	B	0,35	15	0	0	140
Coal	1 Matimba power station 2	1987	2027	665	C	B	0,35	15	0	0	140
Coal	1 Matimba power station 3	1987	2027	665	C	B	0,35	15	0	0	140
Coal	1 Matimba power station 4	1987	2027	665	C	B	0,35	15	0	0	140
Coal	1 Matimba power station 5	1987	2027	665	C	B	0,35	15	0	0	140

Coal	1	1987	2027	665	C	B	0,35	15	0	0	140		Matimba power station 6
Coal	1	1983	2023	600	C	B	0,37	15	0	0	140		Malta power station 1
Coal	1	1983	2023	600	C	B	0,37	15	0	0	140		Malta power station 2
Coal	1	1983	2023	600	C	B	0,37	15	0	0	140		Malta power station 3
Coal	1	1983	2023	600	C	B	0,37	15	0	0	140		Malta power station 4
Coal	1	1983	2023	600	C	B	0,37	15	0	0	140		Malta power station 5
Coal	1	1983	2023	600	C	B	0,37	15	0	0	140		Malta power station 6
Hydro	1	1988	2088	200	P	P			0	0	119	400	Palmiet pumped storage 1
Hydro	1	1988	2088	200	P	P			0	0	119	400	Palmiet pumped storage 2
Gasturbine	1	1976	2016	57	G	P	0,3	15	0	0	100		Port Rex power station 1
Gasturbine	1	1976	2016	57	G	P	0,3	15	0	0	100		Port Rex power station 2
Gasturbine	1	1976	2016	57	G	P	0,3	15	0	0	100		Port Rex power station 3
Coal	1	1985	2025	609	C	B	0,38	15	0	0	140		Tutuka power station 1
Coal	1	1985	2025	609	C	B	0,38	15	0	0	140		Tutuka power station 2
Coal	1	1986	2026	609	C	B	0,38	15	0	0	140		Tutuka power station 3
Coal	1	1986	2026	609	C	B	0,38	15	0	0	140		Tutuka power station 4

Coal	1	1990	2030	609	C	B	0,38	15	0	0	140	
	Tutuka power station 5											
Coal	1	1990	2030	609	C	B	0,38	15	0	0	140	
	Tutuka power station 6											
Hydro	1	1977	2077	120	P	B			0	0	119	466
	Vanderkloof power station 1											
Hydro	1	1977	2077	120	P	B			0	0	119	466
	Vanderkloof power station 2											
coal	1	2006	2046	25	C	B	0,38	15	0	0	140	
coal	1	2006	2046	25	C	B	0,38	15	0	0	140	
Coal	1	2007	2047	50	C	B	0,38	15	0	0	140	
coal	1	2007	2047	50	C	B	0,38	15	0	0	140	
coal	1	2008	2048	100	C	B	0,38	15	0	0	140	
coal	1	2008	2048	100	C	B	0,38	15	0	0	140	
coal	1	2008	2048	50	C	B	0,38	15	0	0	140	
coal	1	2009	2049	100	C	B	0,38	15	0	0	140	
coal	1	2009	2049	100	C	B	0,38	15	0	0	140	
coal	1	2009	2049	75	C	B	0,38	15	0	0	140	
coal	1	2010	2050	100	C	B	0,38	15	0	0	140	
coal	1	2010	2050	50	C	B	0,38	15	0	0	140	

coal	1	2010	2050	50	C	B	0,38	15	0	0	140	
coal	1	2011	2051	50	C	B	0,38	15	0	0	140	
coal	1	2012	2052	100	C	B	0,38	15	0	0	140	
coal	1	2012	2052	100	C	B	0,38	15	0	0	140	
coal	1	2012	2052	100	C	B	0,38	15	0	0	140	
coal	1	2013	2053	50	C	B	0,38	15	0	0	140	
coal	1	2013	2053	50	C	B	0,38	15	0	0	140	
coal	1	2014	2054	25	C	B	0,38	15	0	0	140	
coal	1	2014	2054	25	C	B	0,38	15	0	0	140	
Coal	1	2015	2055	100	C	B	0,38	15	0	0	140	
coal	1	2016	2056	100	C	B	0,38	15	0	0	140	
coal	1	2017	2057	50	C	B	0,38	15	0	0	140	
coal	1	2018	2058	100	C	B	0,38	15	0	0	140	
	Electr		Coal			Oil			Gas			Nuclear
			Sust			CO2	SO2	Nox				
	TWh	%	eff	HR	%	eff	HR	%	eff	HR	%	eff
	HR	%	eff	HR	%	g/kWh	g/kWh	g/kWh				
None	0	0	0,38	27	0	0,4	42	0	0,4	32	0	0
	145	0	0	0	0	50	0,5	0,1				