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Capital naturel et capital humain: trois essais en Afrique Subsaharienne

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Al hamdoulillah !

A mes parents !

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Résumé

L'objectif de cette thèse est d'analyser l'impact du capital naturel sur le capital humain. Elle se focalise sur les pays de l'Afrique Subsaharienne (ASS) qui sont très exposés aux dégradations environnementales. Globalement, les résultats montrent que les conséquences de la dégradation du capital naturel telles que la pollution de l'air ou la perte de la couverture forestière affectent le capital humain et plus précisément la santé des individus en ASS. La thèse se décline en 3 chapitres originaux.

Le chapitre 1 étudie la relation entre la présence d'une aire protégée et le choix de combustible de cuisson en Côte d'Ivoire. L'objectif de la mise en place d'une aire protégée est de lutter contre la déforestation. Toutefois, elle pourrait aussi modifier le choix de combustibles de cuisson des ménages aux alentours. En utilisant les données de l'enquête sur le niveau de vie des ménages de 2015 et un modèle multiniveau à effets mixtes, les résultats montrent que la présence d'une aire protégée augmente la probabilité d'utilisation de la biomasse achetée (bois de chauffe ou charbon de bois) par rapport à l'énergie propre (gaz). L'effet dépend des caractéristiques du chef de ménage, du statut socio-économique du ménage, du niveau de développement de la zone de résidence et du niveau de protection de l'aire protégée. Ainsi, les aires protégées intégrales augmentent la probabilité d'utiliser une énergie propre. En plus d'éclairer les déterminants du choix de combustible, ce chapitre permet de mieux comprendre les conséquences de l'instauration des aires protégées.

La pollution de l'air intérieur constitue un problème de santé publique dans les pays en développement et surtout en ASS où des combustibles solides sont utilisés pour les besoins énergétiques des ménages. Les femmes, habituellement responsables de la cuisine, et leurs jeunes enfants, sont les plus exposés à la pollution de l'air intérieur. Le chapitre 2 analyse la relation causale entre la qualité de l'air intérieur et le risque de maladies respiratoires chez les individus en Côte d'Ivoire en fonction du groupe d'âge. En créant un indicateur original de pollution de l'air intérieur grâce aux données de l'enquête sur le niveau de vie des ménages de 2015 et en utilisant un modèle multiniveau à effets mixtes, l'étude révèle que la pollution de l'air intérieur augmente le risque de maladies respiratoires chez les enfants de moins de 5 ans. L'effet dépend de la présence des aînés âgés entre 5-15 ans, de

la taille et de la zone de résidence du ménage.

Le chapitre 3 s'intéresse à l'impact de la pollution de l'air ambiant sur l'absentéisme scolaire en Afrique du Sud, pays dont l'air ambiant est relativement dégradé. Les données de l'enquête générale des ménages de 2015 et 2016 sont utilisées. En raison de l'exposition non aléatoire à la pollution de l'air, une méthode à variable instrumentale est appliquée. Les instruments utilisés sont les épisodes d'inversion de température, la vitesse et la direction du vent, qui affectent la concentration de polluants dans l'atmosphère. Les résultats montrent qu'une hausse de la concentration de particules fines augmente le risque d'absentéisme chez les enfants âgés entre 5 et 15 ans. L'effet varie en fonction du niveau de richesse, de la taille du ménage, de la structure du ménage, et du sous-groupe de population du chef de ménage. Ce chapitre contribue à la littérature en apportant une réponse claire quant à l'effet de la pollution de l'air ambiant sur l'absentéisme scolaire qui était jusqu'ici mitigé.

Mots clés: capital naturel, capital humain, pollution de l'air, particules fines (PM2.5), santé, éducation, Afrique subsaharienne, Afrique du sud, Côte d'Ivoire.

Summary

This thesis aims to analyse the impact of natural capital on human capital. It focuses on Sub-Saharan African (SSA) countries that are heavily exposed to environmental degradation. Overall, the results of the thesis corroborate that natural capital degradation, such as air pollution and the loss of forest cover, affects human capital and, more specifically, the health of individuals in sub-Saharan Africa. The thesis is divided into three original chapters.

Chapter 1 examines the relationship between the presence of a protected area and the choice of cooking fuel in Côte d'Ivoire. Environmental objectives, namely reducing forest and biodiversity losses, lead to the implementation of protected areas. However, preserving the environment could also change the choice of cooking fuels made by households living near protected areas. Using data from the 2015 Household Living Standards Survey and a multilevel mixed effects model show that a protected area increases the probability of using purchased biomass (firewood or charcoal) compared with clean energy (gas). The effect depends on the characteristics of the household head, the household's socio-economic status, the level of development of the area of residence and the level of protection of the protected area. Thus, integral protected areas increase the probability of using clean energy. Besides shedding light on the determinants of fuel choice, this chapter provides a better understanding of the consequences of establishing protected areas.

Indoor air pollution is a public health problem in developing countries, especially in sub-Saharan Africa, where households mostly rely on solid fuels to cover their energy needs. Women, who are usually responsible for cooking, and their young children are the most exposed to indoor air pollution. Chapter 2 analyses the causal relationship between indoor air quality and the risk of respiratory diseases in individuals in Côte d'Ivoire, according to age group. By creating an original indicator of indoor air pollution using data from the 2015 Household Living Standards Survey and using a multilevel mixed-effects model, the study reveals that indoor air pollution increases the risk of respiratory disease in children under five. The effect depends on the presence of older children aged between 5 and 15 and the household's size and area of residence.

Chapter 3 focuses on the impact of ambient air pollution on school absenteeism in South Africa, of which air quality is relatively poor. It relies on the General household survey data from 2015 and 2016. Due to the non-random exposure to air pollution, the econometric strategy implements an instrumental variable method. The instruments used are temperature inversion episodes, wind speed and wind direction, which affect the concentration of pollutants in the atmosphere. The results show that an increase in the concentration of fine particles increases the risk of absenteeism in children aged between 5 and 15. The effect varies according to the level of wealth, the household size, the household structure, and the population sub-group of the head of household. This chapter adds to the literature that has been delivering mixed results until now by providing a clear answer to the effect of ambient air pollution on school absenteeism.

Keywords: natural capital, human capital, air pollution, fine particles (PM2.5), health, education, Sub-Saharan Africa, South Africa, Ivory Coast.

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Chapter 1

Introduction générale

1.1 Introduction générale: Capital naturel et capital humain en Afrique Subsaharienne

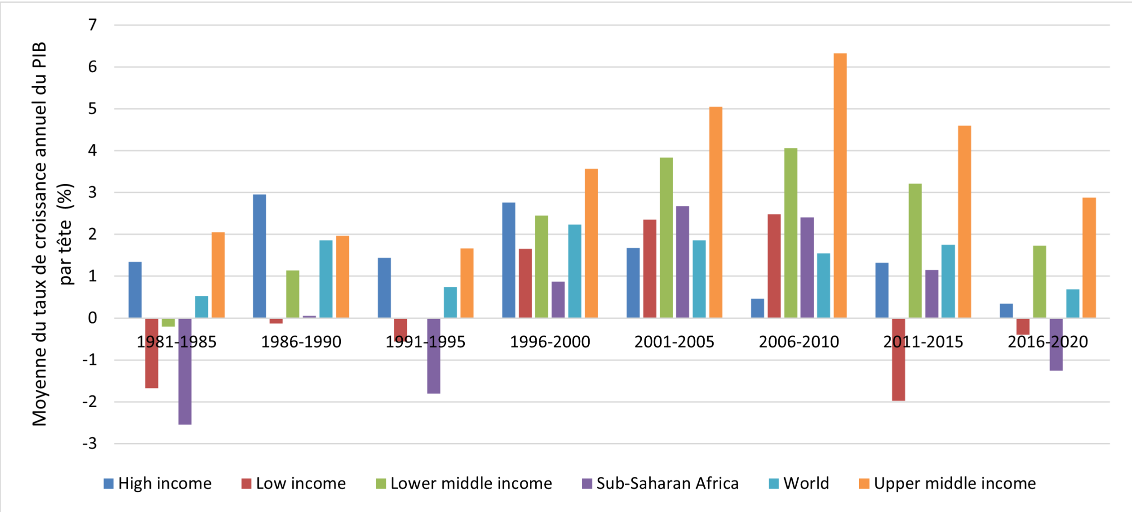
L'Afrique subsaharienne (ASS), une région diverse et très riche en ressources naturelles, est composée de pays à revenu faible, moyen inférieur, moyen supérieur et élevé (World Bank Group, 2023). Malheureusement, cette partie de l'Afrique reste confrontée à plusieurs défis en matière de développement économique. Durant la période 1981-2020, la région a connu une tendance non linéaire de son taux de croissance. En effet, entre 1981-1995, le taux de croissance du Produit Intérieur Brut (PIB) par tête a baissé suivie d'une hausse entre 1996-2010. Le taux de croissance a ensuite chuté entre 2011-2015 et devient négatif durant le quinquennal 2016-2020. Entre 1981 et 2020, la baisse du taux de croissance du PIB par tête est plus élevée durant le quinquennal 1981-1985.

Les performances économiques de long terme en Afrique sont assez contrastées. La croissance est plus faible comparée à d'autres régions, notamment les pays de l'OCDE, vers la fin du 20e siècle. Cette faible performance économique est qualifiée de "tragique" par Artadi and Sala-i Martin (2003) car elle a eu d'énormes conséquences sur le bien-être humain dû à la hausse du niveau de pauvreté sur le continent. La baisse de croissance s'est suivie d'une phase d'amélioration au début des années 2000 comparativement à d'autres régions du monde. Cela a fait naître l'espoir d'un avenir économique meilleur pour le continent après des décennies de déclin (Rodrik, 2018). Ces phases contrastées de performances économiques de long terme suscitent une question importante: qu'est ce qui détermine le développement économique de la région ?

Artadi and Sala-i Martin (2003) listent les conditions pour que les économies africaines se développent. Il faudrait garantir la sécurité, mettre en place des institutions qui garantissent l'État de droit et les droits de propriété, investir dans le capital humain, réduire les distorsions politiques qui rendent les investissements excessivement coûteux, réduire des dépenses inutiles de l'Etat, et enfin s'ouvrir économiquement, ce qui favoriserait les flux de commerce, d'investissements directs étrangers (IDE) et de diffusion de technologie. Les auteurs soulignent la nécessité d'accumuler du capital humain pour une meilleure performance économique africaine. Cela est possible grâce aux investissements dans l'éducation et la santé de la population. De plus, selon les prévisions et les statistiques démographiques des Nations Unies (Figure 1.2), la population mondiale devrait atteindre environ 10,4 milliards d'individus d'ici la fin du siècle selon le scénario médian. Une bonne partie de cette croissance démographique mondiale aura lieu en Afrique car elle devrait atteindre environ 4 milliards d'individus d'ici 2100 soit environ 38% de la population mondiale et la population de l'ASS représentera à elle seule 32% de la population mondiale (Figure 1.2). Pour une meilleure performance économique de la région, il est plus que nécessaire de renforcer le capital humain en tirant profit du dividende démographique qui sera déterminant dans le développement économique du continent au 21e siècle.

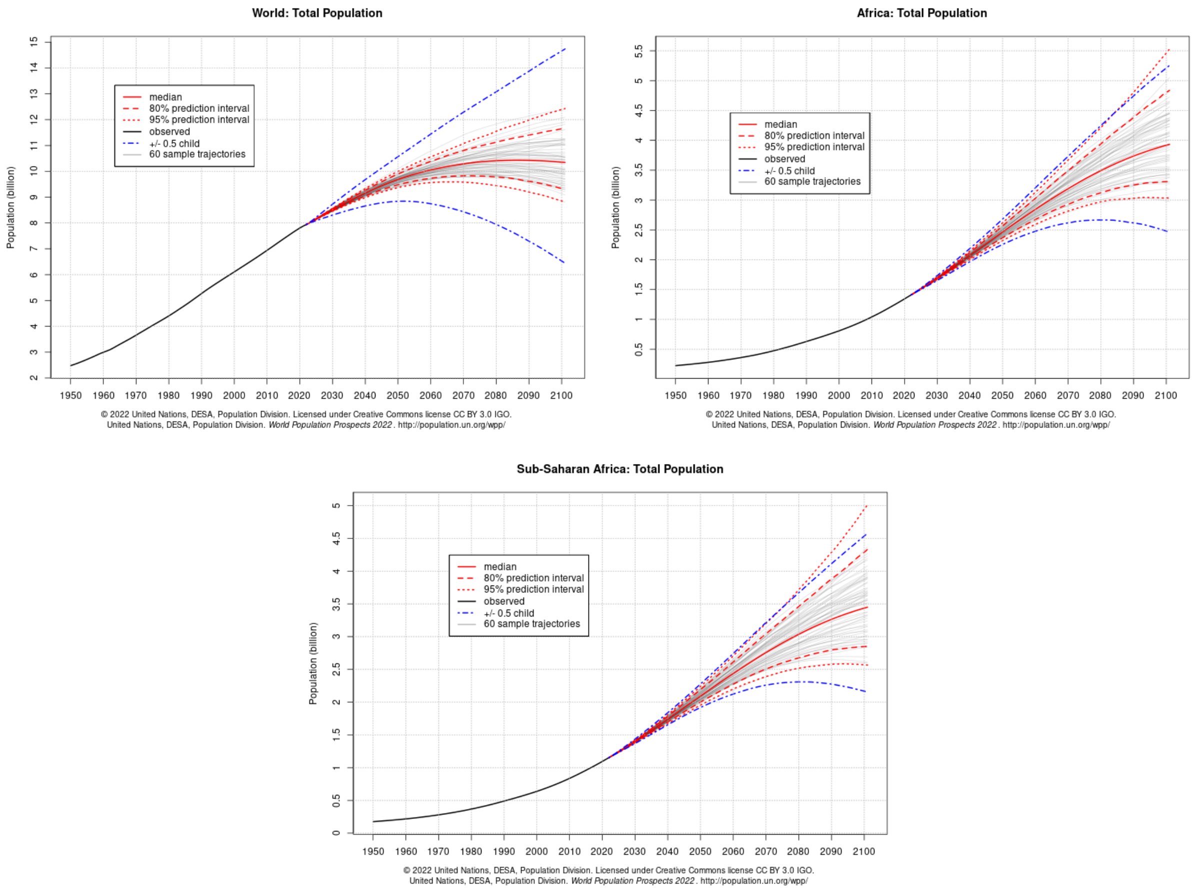
Le capital humain est pris en compte dans les objectifs de Développement Durable (ODD). Nommés également objectifs mondiaux, les ODD ont été adoptés par les Nations Unies en 2015. Il s'agit d'un appel mondial à agir pour éradiquer la pauvreté, protéger la planète et faire en sorte que tous les êtres humains vivent dans la paix et la prospérité. De ce fait, les ODD comportent 17 objectifs pour 2030 dont cent-soixante-neuf cibles et deux cent trente indicateurs. Le capital humain est représenté à travers les troisième, septième et treizième ODD. En effet, ceux-ci s'intéressent respectivement à la préservation de la santé et le bien être de la population, à la fourniture d'une énergie propre et à un coût abordable, et la mise en place des mesures relatives à la lutte contre les changements climatiques d'ici 2030. Les préoccupations auxquelles ces 3 ODD devraient répondre sont très importantes pour le développement du capital humain des pays et surtout celui de l'ASS.

Figure 1.1: Moyenne du taux de croissance annuel du PIB par tête entre 1981-2020



Source : Propre élaboration de l'auteur en utilisant les World Developpement Indicators de la Banque Mondiale.

Figure 1.2: Projections des Nations Unies de la population mondiale et africaine



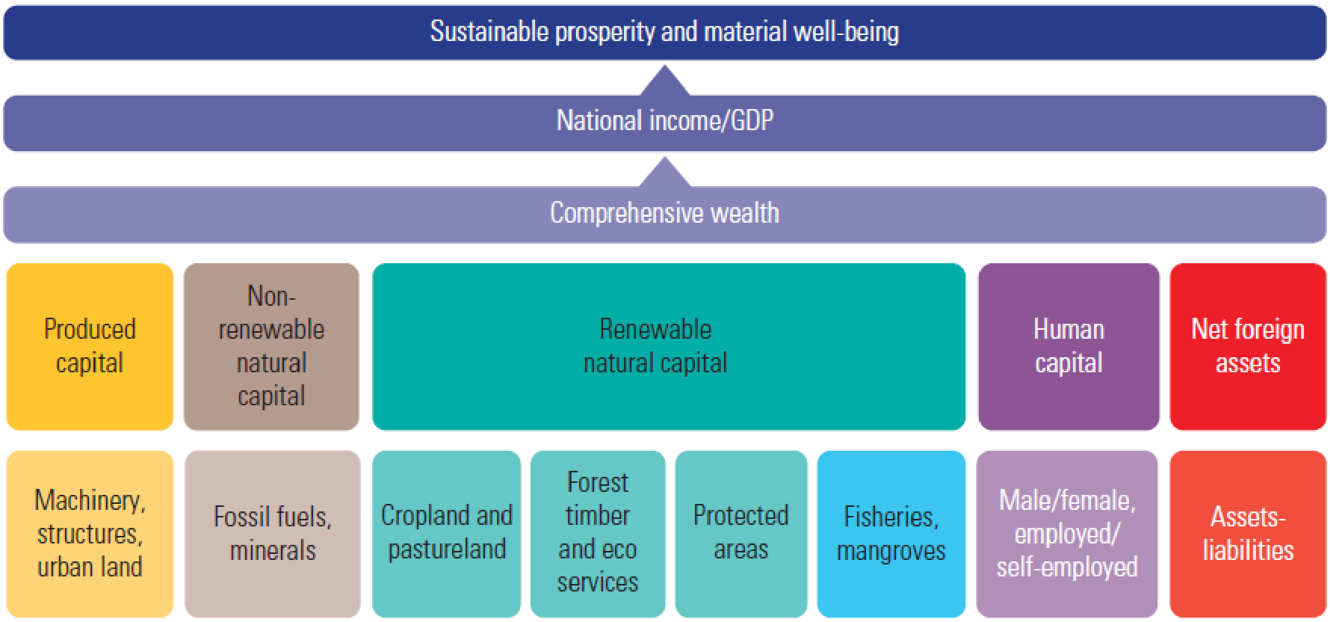
Source : United Nations, DESA, Population division. World Population Prospects 2022

1.1.1 Contribution du capital humain et capital naturel au développement économique

Le terme "capital" provient de l'économie classique et néo-classique et définit un stock qui peut être organisé en classes appelées actifs et qui a le potentiel de produire d'autres biens ou utilités au profit des sociétés humaines (Ekins et al., 2003; Mace et al., 2015). Il existe trois grands types de capital: le capital humain, le capital manufacturé ou produit et le capital naturel.

Le Produit Interieur Brut (PIB), un indicateur important de l'activité économique, est une mesure de flux qui saisit le revenu ou la production sur une période donnée. Cet indicateur présente une limite car il ne reflète pas la dépréciation, l'épuisement et la dégradation des actifs utilisés. Par conséquent, utilisé seul, le PIB peut fournir des signaux trompeurs sur l'état de l'économie, l'efficacité de l'utilisation des actifs et la durabilité du développement. C'est dans ce sens que la Banque Mondiale a mis en place un indicateur de la richesse totale des nations qui tient compte du capital produit, du capital humain, du capital naturel et des avoirs étrangers nets (Figure 1.3). Ainsi, pour évaluer les performances économiques d'un pays, il est important de suivre à la fois le PIB et la richesse totale.

Figure 1.3: Structure des comptes patrimoniaux globaux

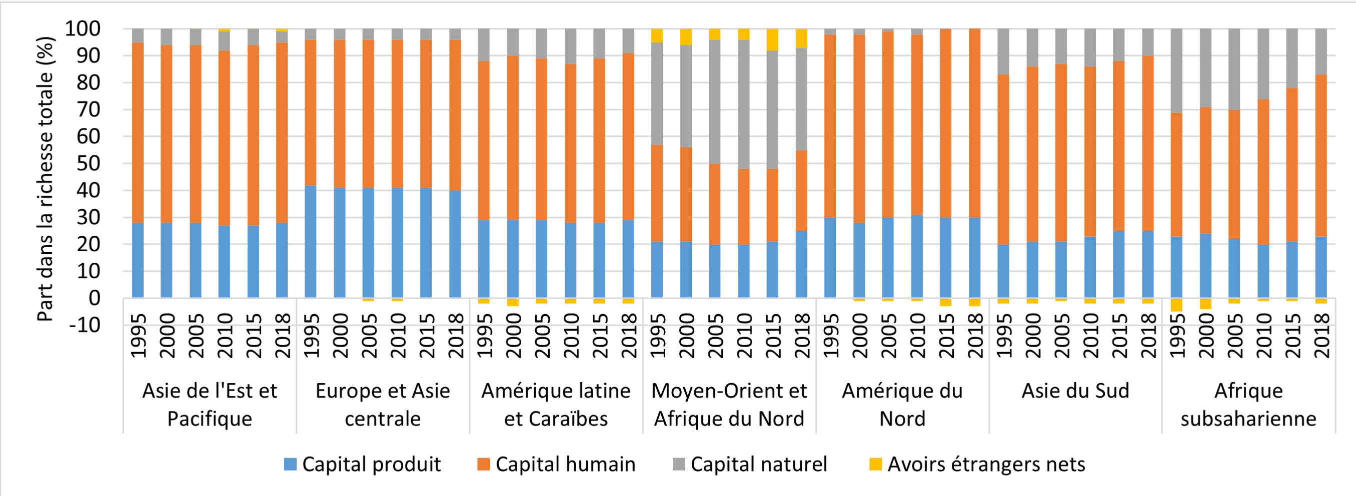


Source: The World Bank, The Changing Wealth of Nations 2021

Le capital naturel est la valeur combinée de tout ce qui provient de la nature. Il regroupe entre autres les créatures vivantes, l'eau, l'air et le sol, et procure aux êtres humains les moyens essentiels dont ils ont besoin pour vivre. Le capital naturel est créé par des processus biogéophysiques plutôt que par l'action humaine et représente la capacité de l'environnement à répondre aux besoins humains, que ce soit en fournissant des matières premières ou des services (Hamilton and Clemens, 1999; Natural Capital Committee and others, 2013). Ces services comprennent les cycles biochimiques mondiaux dans le maintien des conditions écologiques propices à la vie humaine (Hamilton and Clemens, 1999). Ainsi, le capital naturel produit des intrants productifs qui, combinés aux intrants humains et produits, génèrent des biens qui procurent des avantages de valeur à la société (Edens and Hein, 2013; Mace et al., 2015).

Par ailleurs, selon la Banque Mondiale, *le capital humain correspond à l'ensemble des connaissances, compétences et conditions de santé que les individus accumulent tout au long de leur vie et qui leur permet de réaliser pleinement leur potentiel en devenant des membres productifs de la société.* Cette définition révèle que les composantes essentielles du capital humain sont la santé et l'éducation. En effet, la théorie du capital humain se concentre non seulement sur l'éducation mais aussi sur la santé de l'individu en tant qu'intrant de la production économique (Osiobe et al., 2019). Ainsi, le capital humain est considéré comme un facteur de production qui, combiné au capital physique (Mincer, 1984), est essentiel pour la croissance économique de nos pays.

Figure 1.4: Part des différentes formes de capital dans la richesse totale par région



Source: The World Bank, The Changing Wealth of Nations 2021

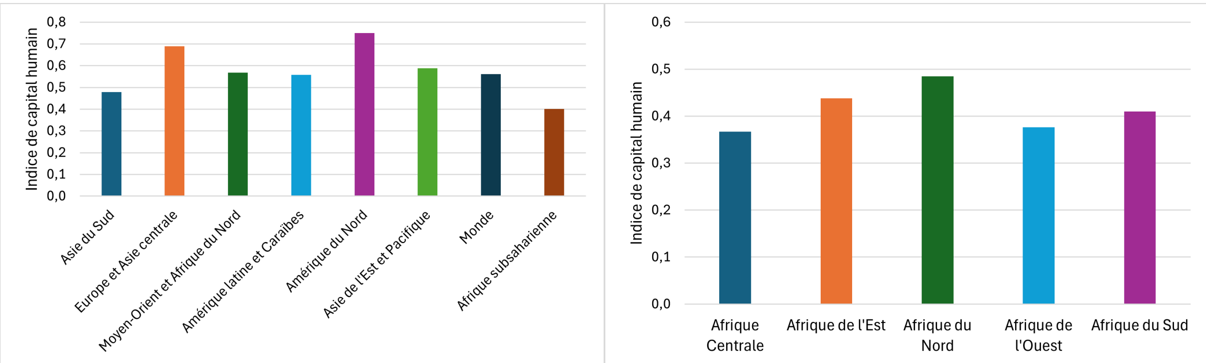
La contribution du capital naturel et du capital humain dans la richesse totale des pays est indéniable et varie selon les régions entre 1995 et 2018 (Figure 1.4). Le capital humain constitue une part importante qui augmente au cours du temps et représente plus de 50% de la richesse totale dans certaines régions. Cette tendance est également observée en ASS, où on observe une hausse de la part du capital humain sur la période. Par contre, la part du capital naturel tend à baisser au cours du temps sauf dans la région du Moyen Orient et Afrique du Nord où le capital naturel représente 38% de la richesse totale. Le capital humain et le capital naturel combinés représentent en moyenne environ 72% de la richesse totale dans le monde entre 1995 et 2018. Ils contribuent fortement au développement économique des pays.

1.1.2 Démographie, capital humain et développement économique

La population totale de l'ASS devrait atteindre environ 3,5 milliards d'individus d'ici la fin du siècle (Figure 1.2). Cette taille estimée de la population peut engendrer un dividende démographique favorable à la croissance économique à travers le renforcement du capital humain. Le dividende démographique est défini comme le bénéfice de l'augmentation de la part de la population active. Il s'agit donc d'une période propice pour investir dans la santé et l'éducation et développer ainsi le capital humain. Pour profiter pleinement du dividende démographique en ASS, les politiques de renforcement du capital humain doivent être suivies par des politiques de création d'emplois pour la population active sans quoi les espoirs de développement qu'il suscite ne peuvent que rester vains.

Le capital humain reste limité dans la région (World Bank Group, 2023). En effet, d'après le nouvel indice de capital humain mis au point par la Banque Mondiale qui mesure le niveau de productivité potentielle de la prochaine génération de travailleurs, l'ASS a l'indice le plus faible parmi toutes les régions du monde (Figure 1.5). En 2020, la moyenne de l'indice est estimée à 0,4 ce qui est inférieur à la moyenne mondiale de 0,56. La valeur de l'indice montre que dans l'état actuel des choses, un enfant né en 2020 en ASS à l'âge adulte ne pourrait espérer atteindre que 40% seulement de son niveau de productivité s'il bénéficiait d'une éducation complète et d'une santé totale. Il existe une disparité à l'intérieur du continent africain car l'Afrique du Nord et de l'Est se distinguent avec une valeur de l'indice supérieure à la moyenne de l'ASS (Figure 1.5). Au regard de l'importance du capital humain dans la richesse totale des nations (Figure 1.4), son faible niveau agit directement sur le bien-être des individus et sur l'économie des pays en ASS.

Figure 1.5: Indice de capital humain en 2020



Source : Propre élaboration de l'auteur en utilisant les données de la Banque Mondiale.

Selon le rapport de la Banque Mondiale sur le "Africa Human Capital Plan" (The World Bank, 2019), la faiblesse du capital humain en ASS s'expliquerait par la mortalité infantile et maternelle, l'éducation et la malnutrition. Le point commun de ces facteurs est le niveau de pauvreté qui reste élevé dans la région. Cela se traduit par une dépendance de la population de l'ASS au capital naturel.

1.1.3 Dégradation du capital naturel

Les enjeux environnementaux suite à la dégradation du capital naturel sont de plus en plus importants. La surexploitation du capital naturel entraîne de nombreux dommages environnementaux qui augmentent plus rapidement que prévu (PNUE, 2017). Cela se traduit entre autres par le changement climatique, l'érosion des sols, la pollution de l'air, la perte de la biodiversité et des habitats sauvages tels que les forêts et les zones humides. La dégradation du capital naturel impose des coûts externes à la société et aux générations futures. Dans le cadre de cette thèse nous nous intéressons spécifiquement à la pollution de l'air et à la déforestation. Les lignes suivantes donnent un aperçu de l'état des lieux en ce qui concerne la qualité de l'air et la perte de la couverture forestière en ASS.

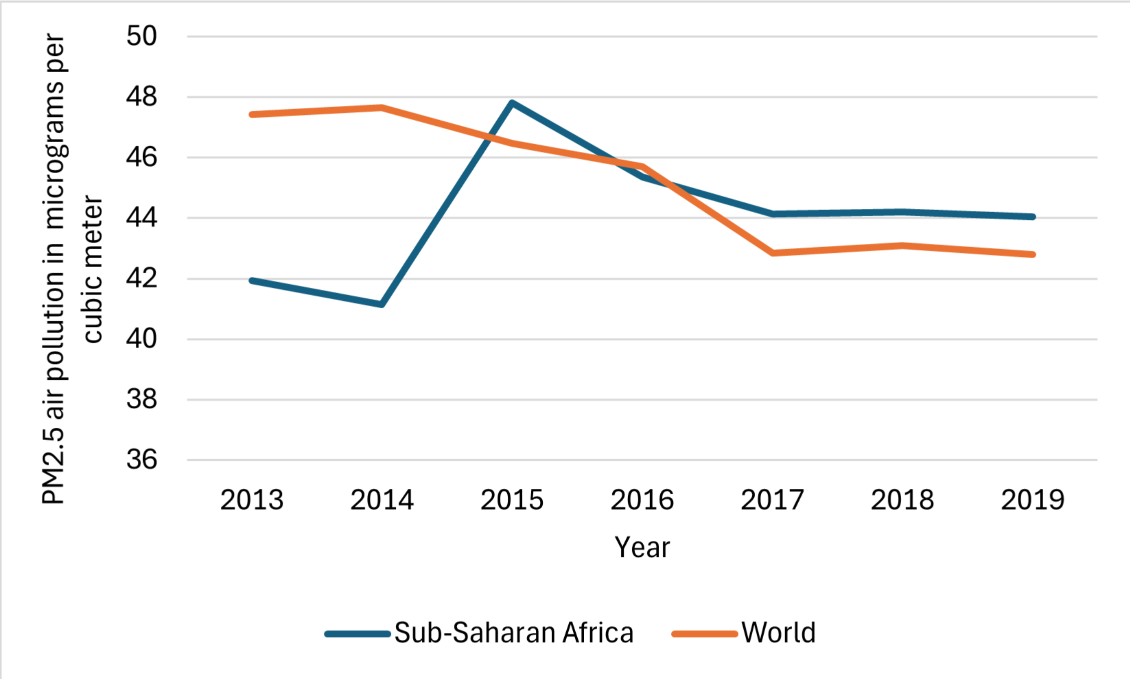
La pollution de l'air

Selon l'Organisation Mondiale de la Santé (OMS), "la pollution de l'air est la contamination de l'environnement intérieur ou extérieur par tout agent chimique, physique ou biologique qui modifie les caractéristiques naturelles de l'atmosphère" (Organisation Mondiale de la Santé, 2024). Les polluants les plus néfastes pour la santé humaine sont les particules en suspension, le monoxyde de carbone, l'ozone, le dioxyde d'azote et le dioxyde de soufre. Les sources de pollution atmosphérique les plus fréquentes sont les véhicules à moteur, les appareils à combustion d'usage domestique, les installations industrielles et les incendies de forêt.

En ce qui concerne la pollution de l'air ambiant, toutes les régions terrestres ne sont pas exposées au même niveau de pollution. Bien que l'on constate une tendance à la baisse du niveau d'exposition aux particules fines (PM2.5) entre 2015 et 2019 dans le monde, l'ASS continue d'enregistrer un niveau d'exposition aux particules fines (PM2.5) plus élevé que le niveau mondial entre 2015 et 2019 (Figure 1.6). Ce niveau de pollution n'est pas sans conséquence sur la santé des individus car il est à l'origine de maladies respiratoires, cardiovasculaires et autres, et constitue une cause importante de morbidité et de mortalité. Selon l'OMS, la quasi-totalité de la population mondiale (99%) respire un air pollué.

En plus de la pollution de l'air ambiant, la pollution de l'air intérieur constitue également un problème majeur de santé publique. Elle est générée par l'utilisation de combustibles et de technologies inefficaces et polluants à l'intérieur et autour des habitations. Elle contient des polluants nocifs pour la santé, notamment des particules fines qui pénètrent profondément dans les poumons et s'infiltrent dans la circulation sanguine. Selon l'OMS, dans les habitations moins ventilées, la fumée intérieure peut contenir des niveaux de particules fines 100 fois supérieurs au niveau acceptable (Organisation Mondiale de la Santé, 2023a). Les femmes généralement responsables des tâches ménagères telles que la cuisine et la collecte de bois de chauffage, sont les plus exposées à la pollution de l'air intérieur ainsi que les enfants. Ce type de pollution est à l'origine des maladies non transmissibles telles que le cancer du poumon, les cardiopathies ischémiques, les broncho-pneumopathies chroniques obstructives et les accidents vasculaires cérébraux (Organisation Mondiale de la Santé, 2023a).

Figure 1.6: Exposition annuelle moyenne à la pollution atmosphérique par les PM2.5 en microgrammes par mètre cube

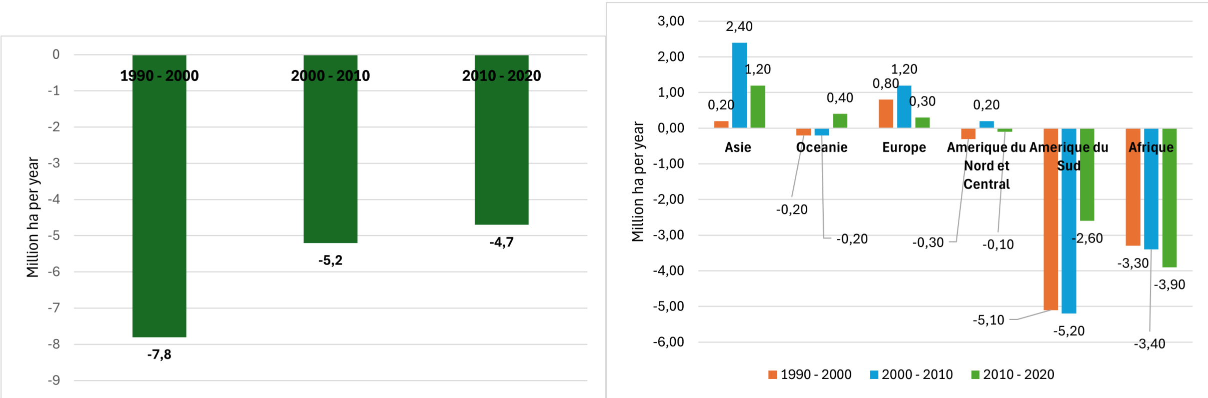


Source : Propre élaboration de l'auteur en utilisant les World Developpement Indicators de la Banque Mondiale.

La perte de la couverture forestière

La superficie forestière mondiale est estimée à 4,06 milliards d'hectares (ha), ce qui équivaut à 31% de la superficie totale des terres (FAO, 2020). Les cinq pays qui abritent plus de la moitié (54%) des forêts mondiales sont la Russie, le Brésil, le Canada, les États-Unis d'Amérique et la Chine (FAO, 2020). Depuis 1990, le monde a perdu 178 millions d'hectares de forêts, même si le rythme des pertes a diminué entre 1990 et 2020. En effet, d'après la Figure 1.7, la perte forestière est passée de 7,8 millions ha par an entre 1990-2000 à 5,2 millions ha par an entre 2000-2010 et à 4,7 million ha par an lors de la décennie 2010-2020. Ces chiffres montrent une diminution de la perte forestière qui pourrait s'expliquer par la baisse de la déforestation dans certains pays et l'augmentation de la superficie forestière dans d'autres grâce au boisement et à l'expansion naturelle des forêts (FAO, 2020).

Figure 1.7: Variation annuelle nette de la superficie forestière dans le monde, par region et par décennie entre 1990-2020



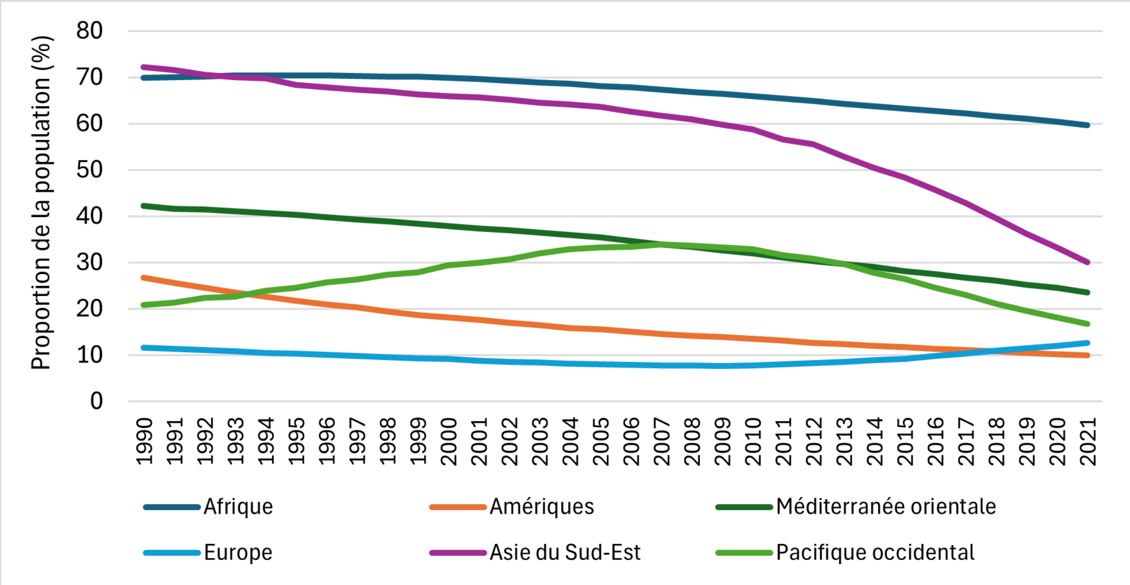
Source: Propre élaboration de l'auteur en utilisant les données du Global Forest Resources Assessment (FAO, 2020)

Malgré la réduction de la perte de la couverture forestière au niveau mondial, elle reste faible en Afrique par rapport aux autres régions. Le graphique 1.7 montre qu'au cours de la récente décennie (2010-2020), l'Afrique enregistre le taux annuel de perte nette de forêts le plus élevé avec 3,9 millions d'hectares, suivie par l'Amérique du Sud, avec 2,6 millions d'hectares. Nous observons cette tendance à la hausse du taux annuel de perte nette de forêts en Afrique au cours de chacune des trois décennies depuis 1990 par rapport aux autres régions. Cela montre une accentuation de la déforestation en Afrique depuis 1990.

Dans la région africaine, les causes de la déforestation sont nombreuses et variées. Elles concernent principalement les activités agricoles, l'agro-industrie, les activités minières, l'urbanisation et la demande en bois-énergie. Ce dernier facteur constitue un facteur très important de la déforestation car les ménages africains sont très dépendants de la biomasse. En effet, la proportion de la population africaine qui utilise la biomasse (bois de chauffe, charbon de bois) pour cuisiner est d'environ 60% en 2021 (Figure 1.8). Entre 1990-2021, dans presque toutes les régions du monde, il y a une tendance à la baisse en ce qui concerne l'utilisation de la biomasse pour la cuisine. L'Afrique enregistre toutefois une baisse relativement faible (Figure 1.8). La région a encore du chemin à faire pour diminuer l'utilisation de la biomasse de cuisson et ralentir la déforestation d'une part et préserver la santé des ménages d'autre part.

La section suivante s'intéresse à la relation entre la capital naturel et le capital humain.

Figure 1.8: Proportion de la population utilisant la biomasse (bois de chauffe, charbon de bois) comme combustible de cuisson entre 1990-2021



Source: Propre élaboration de l'auteur en utilisant les données de l'Organisation Mondiale de la Santé

1.1.4 Dégradation du capital naturel et capital humain

La dégradation du capital naturel affecte le capital humain, notamment, la pollution de l'air (Kampa and Castanas, 2008; Carson, 2010; Graff Zivin, 2012, 2013; Hanna, 2015). La pollution atmosphérique constitue l'un des grands risques pour la santé liée à l'environnement. En effet, la pollution de l'air ambiant et à l'intérieur des habitations est à l'origine respectivement d'environ 339000 et 639000 décès prématurés en 2019 en Afrique (Organisation Mondiale de la Santé, 2023b).

L'exposition des individus à la pollution de l'air n'est pas aléatoire car elle dépend de plusieurs facteurs. En ASS, le facteur essentiel constitue les ressources financières. En effet, l'extrême pauvreté sévit dans la région car environ 462 millions de personnes y sont encore exposées en 2023 (World Bank Group, 2023). Ce niveau de pauvreté pousse la population à être très dépendante et exposée au capital naturel. Ainsi, la pauvreté peut affecter entre autres le choix de combustible des ménages ou le choix du lieu de résidence. Les contraintes financières peuvent conduire un ménage à utiliser un combustible polluant comme la biomasse végétale qu'il peut acheter à moindre coût ou collecter directement dans les forêts. Selon Dagnachew et al. (2020), près de 900 millions de personnes en ASS utilisent la biomasse végétale pour cuisiner. L'utilisation de ce genre de combustible constitue une source de pollution de l'air intérieur si la combustion est incomplète et a des répercussions sur la biodiversité, le climat et la santé.

D'après l'OMS, les décès provoqués par la mauvaise qualité de l'air intérieur sont dus à des cardiopathies ischémiques (32%), à des infections des voies respiratoires inférieures (21%), à des accidents vasculaires cérébraux (23%), à des bronchopneumopathies chroniques obstructives (19%) et à des cancers du poumon (6%). Les enfants de moins de 5 ans ne sont pas épargnés car leur exposition à la pollution de l'air domestique est responsable de près de la moitié des décès par pneumonie. L'exposition peut également être à l'origine d'un faible poids à la naissance, d'asthme, d'otites, d'infections des voies respiratoires supérieures, de tuberculose, de cataracte, de cancers du nasopharynx et du larynx, et de cancer du col de l'utérus. Ce type de pollution était responsable d'environ 3,2 millions de décès par an en 2020 dans le monde, dont plus de 237 000 décès d'enfants de moins de 5 ans (Organisation Mondiale de la Santé, 2023a). Les effets combinés de la pollution de l'air ambiant et de la pollution de l'air domestique sont associés à 6,7 millions de décès prématurés par an dans le monde (Organisation Mondiale de la Santé, 2023a). Il est donc primordial de développer l'utilisation de combustibles et de technologies propres pour réduire la pollution de l'air dans les habitations et protéger la santé. Il s'agit notamment de l'énergie solaire, de l'électricité, du biogaz, du gaz de pétrole liquéfié (GPL), du gaz naturel, des carburants à base d'alcool, ainsi que des fourneaux à biomasse qui respectent les objectifs d'émission fixés par les normes de l'OMS (Organisation Mondiale de la Santé, 2023a). La Côte d'Ivoire, pays auquel nous nous intéressons dans la thèse pour traiter ce sujet, tente de diminuer au maximum l'utilisation des combustibles polluants et de préserver ainsi la couverture forestière à l'horizon 2030 à travers le Plan d'Actions National des Energies Renouvelables (PANER) (Ministère du Pétrole et de l'Energie, 2016).

Les ressources financières constituent l'un des facteurs qui peut affecter le choix de localisation des ménages (Tiebout, 1956). De ce fait, le manque de moyens financiers peut les inciter à choisir des zones où les logements coûtent moins cher et ces zones pourraient se caractériser par une mauvaise qualité de l'air ambiant. Parmi les pays exposés à la pollution de l'air ambiant en ASS, l'Afrique du Sud n'est pas un bon élève. Son niveau de pollution de l'air ambiant s'expliquerait par le développement des industries surtout extractives et la densité du trafic routier. Pour pallier ce problème de pollution de l'air, le pays a mis en place depuis 2004 une politique de régulation de la qualité de l'air (2004 Air Quality Act). Parmi les polluants visés figurent les particules fines (PM 2.5) qui sont très néfastes pour la santé humaine.

Cependant, le lien entre le capital naturel et le capital humain en ASS n'est pas suffisamment étudié. Ce besoin de connaissances est plus que nécessaire pour définir les bonnes politiques publiques. Ainsi, l'objectif des travaux de cette thèse est de contribuer à la littérature sur la relation qui existe entre le capital humain et le capital naturel et quantifier ainsi les différents impacts socio-économiques de la dégradation du capital naturel en ASS.

1.1.5 Contribution de la thèse

Les travaux conduits dans le cadre de cette thèse s'intéressent à l'impact du capital naturel sur le capital humain en ASS. La thèse se décline en 3 chapitres originaux.

Le chapitre 2 fournit une analyse détaillée de la relation entre la présence d'une aire protégée et le choix de combustible de cuisson en Côte d'Ivoire. Étant donné que la mise en place des aires protégées pourrait réduire la déforestation et affecter le statut économique des ménages aux alentours, l'objectif de l'étude est de savoir si cela conduirait à une transition énergétique vers les combustibles modernes plus propres ou à une utilisation simultanée des combustibles traditionnels et modernes par les ménages. Ce chapitre teste cette hypothèse en utilisant les données de l'enquête sur le niveau de vie des ménages ivoiriens de 2015 et la World Database on Protected Areas (WDPA). En raison de la structure des données qui sont au niveau des ménages et des sous-préfectures, nous utilisons un modèle logit multiniveaux à effets mixtes. En outre, au regard de la distribution non aléatoire des aires protégées, nous prenons en compte les caractéristiques de la sous-préfecture pouvant influencer la localisation des aires protégées. Cette étude est la première à s'intéresser à l'impact des aires protégées sur le choix de combustible de cuisson des ménages ivoiriens. Les résultats obtenus montrent qu'une hausse du coût d'accès à la forêt à travers la mise en place d'une aire protégée dans une sous-préfecture affecte le choix de combustible de cuisson des ménages vivant dans la localité. La présence de l'aire protégée augmente la probabilité d'utilisation de la biomasse achetée (bois de chauffe ou charbon de bois) par rapport à l'énergie propre (gaz) de 6,78 points de pourcentage. De plus, l'effet de la présence de l'aire protégée dépend du type et du niveau de protection de l'aire protégée, ainsi que de la zone de résidence. L'impact de l'aire protégée varie lorsqu'il s'agit d'un parc, d'une réserve naturelle ou d'une forêt classée. Lorsqu'il s'agit d'une aire protégée intégrale, cela augmente la probabilité d'utilisation de l'énergie propre (gaz). La présence d'une aire protégée dans une sous-préfecture peu développée augmente la probabilité d'utilisation de la biomasse collectée et quand il s'agit d'une zone urbaine, la présence de l'aire protégée augmente le risque d'utilisation de la biomasse achetée. Par ailleurs, certains facteurs, tels que les caractéristiques du chef de ménage et le statut socio-économique du ménage, affectent le choix du combustible de cuisson des ménages. Le cas de la Côte d'Ivoire est intéressant car le gouvernement a mis en place le Plan d'Action National des Energies Renouvelables dont certains objectifs spécifiques sont la préservation de la couverture forestière, l'augmentation de l'accès aux énergies propres et la réduction de la demande d'énergies polluantes plus précisément la réduction de la quantité de bois-énergies utilisée pour la satisfaction des besoins énergétiques des ménages (Ministère du Pétrole et de l'Energie, 2016). Toutefois, des efforts supplémentaires restent à fournir si le pays veut procurer l'énergie propre à la population à l'horizon 2030 et préserver la couverture forestière. Cette étude permet de contribuer à la littérature en fournissant des éléments de compréhension en ce qui concerne les conséquences de la mise en place des aires protégées en ASS. Au delà de la déforestation, la mise en place d'une aire protégée affecte le choix énergétique des ménages et donc la santé.

La pollution de l'air intérieur constitue un problème de santé publique dans les pays en développement et surtout en ASS où des combustibles solides (charbon et biomasse) sont utilisés pour les besoins énergétiques des ménages. Les femmes, qui sont habituellement responsables de la cuisine, et leurs jeunes enfants, sont les plus exposés à la pollution de l'air qui en résulte. L'objectif du chapitre 3 est d'analyser la relation causale entre la qualité de l'air intérieur et le risque de maladies respiratoires chez les individus en Côte d'Ivoire en fonction du groupe d'âge. En utilisant les données de l'enquête sur le niveau de vie des ménages de 2015 et la base de données satellites de van Donkelaar et al. (2018) qui contient les concentrations annuelles de particules fines au niveau du sol (PM2.5), nous créons un indicateur original de pollution de l'air intérieur pour approximer le niveau de pollution à laquelle les individus sont exposés quand ils sont à l'intérieur de la maison. Cet indicateur créé à partir des sources de pollution de l'air intérieur permet de combler le manque d'information sur la qualité de l'air intérieur dans la base de données. Les données sur la luminosité nocturne, provenant d'imagerie satellitaire issue de la base de données du Earth Observations Group, sont également utilisées et permettent d'avoir des informations sur le niveau de développement des sous-préfectures. L'étude est basée sur un échantillon de 2060 personnes qui avaient consulté un prestataire de soins de santé au cours des quatre dernières semaines au moment de l'enquête et réparties en quatre groupes d'âge. Les enfants de moins de 5 ans constituent le premier groupe. Le deuxième groupe est constitué d'enfants âgés de 5 à 14 ans. Le troisième groupe comprend les personnes âgées de 15 à 64 ans qui sont considérées comme des personnes actives. Enfin, le quatrième groupe est celui des personnes âgées de 65 ans et plus. Le rapport de dépendance est utilisé pour créer ces groupes d'âge afin de voir comment l'impact sanitaire de la pollution de l'air intérieur varie en fonction du groupe. Un modèle logit multiniveaux à effets mixtes est utilisé en raison de la structure des données qui sont au niveau des sous-préfectures, des ménages et individuel. Les résultats de l'étude montrent que la pollution de l'air intérieur augmente le risque de maladies respiratoires de 1.64% chez les enfants de moins de 5 ans. L'effet dépend de la présence de grands frères et soeurs âgés entre 5-15 ans, de la taille et de la zone de résidence du ménage. Cette étude est la première à répondre à cette question en utilisant un indicateur innovant de qualité de l'air intérieur pour pallier l'indisponibilité des données au niveau national dans un pays d'ASS comme la Côte d'Ivoire.

Une meilleure qualité de l'air ambiant est importante pour la santé étant donné le temps passé à l'extérieur des maisons. D'après l'OMS, plus de 90 % des personnes vivent dans un endroit qui ne répond pas aux normes en matière de qualité de l'air et la partie du globe exposée à la pollution particulaire est essentiellement constituée de pays en développement (World Health Organization, 2016). Le chapitre 4 s'intéresse à l'impact de la pollution de l'air ambiant sur l'absentéisme scolaire en Afrique du Sud, pays dont l'air ambiant n'est pas de très bonne qualité. Le choix de l'Afrique du Sud est intéressant dans la mesure où le pays a mis en place depuis 2004 une politique de régulation de la qualité de l'air (2004 Air Quality Act). Parmi les polluants visés, il y a les particules fines (PM2.5) qui sont très néfastes pour la santé humaine et que nous utilisons pour approximer la qualité de l'air ambiant. Les PM2.5 sont à l'origine de la mortalité due aux maladies respiratoires et cardiovasculaires. Celles-ci peuvent agir sur les performances économiques des pays, à travers leur impact sur le capital humain. Dans cette étude, nous nous intéressons particulièrement à l'absentéisme scolaire. Les analyses antérieures qui ont testé la relation entre la pollution aux particules et l'absentéisme scolaire trouvent un effet positif, négatif ou nul. A notre connaissance, cette étude est la première à s'intéresser à cette question dans le cas d'un pays d'ASS, les études précédentes étant focalisées sur les Etats-Unis, le Japon et la Corée du Sud. Les données de l'enquête générale des ménages de l'Afrique du Sud en 2015 et 2016 et les données de van Donkelaar et al. (2018) sur la concentration moyenne annuelle des PM2.5 sont utilisées. L'exposition des individus à la pollution de l'air n'est pas aléatoire car dépend de certains facteurs tels que les ressources financières qui pourraient affecter le choix de localisation des individus (Tiebout, 1956). La distribution non aléatoire de l'exposition à la pollution de l'air pourrait être à l'origine d'un problème d'endogénéité si nous utilisons directement les données de PM2.5. Dans le but d'éviter ce problème d'endogénéité dû au biais de variables omises, nous utilisons une méthode à variable instrumentale. Les instruments utilisés affectent la concentration des polluants dans l'atmosphère et sont la vitesse du vent, la direction du vent et le nombre d'épisodes d'inversion de température. Ces instruments sont extraits des images satellitaires de la NASA. L'épisode d'inversion de température est un phénomène qui implique une augmentation de la température avec l'altitude alors que la théorie indique le contraire. Pour obtenir l'information sur l'instrument, nous utilisons des pixels d'environ 25 km. Pour chaque pixel, nous faisons la différence entre la température quotidienne à 1000 hpa et la température à 925 hpa. La température à 1000 hpa correspond aux conditions de surface et la température à 925 hpa correspond aux conditions à environ 600 m au-dessus du niveau de la mer. Nous calculons ensuite pour chaque province le nombre de pixels où le résultat est négatif, c'est-à-dire où il y a eu une inversion de température. Cela permet d'obtenir le nombre d'épisodes d'inversion de température par province pour chaque année. Les résultats de l'étude révèlent qu'une augmentation de la concentration de PM2.5 de 10 $\mu g/m^3$ entraîne un risque d'absentéisme de 1,33 à 2,46 points de pourcentage chez les enfants âgés entre 5 et 15 ans. L'effet varie en fonction du niveau de richesse, de la taille du ménage, de la structure du ménage, et du sous-groupe de population (asiatiques, blancs, indiens, métissés, noirs) du chef de ménage. Ce chapitre contribue à la littérature en apportant une réponse claire quant à l'effet de la pollution de l'air ambiant sur l'absentéisme scolaire qui était jusqu'ici mitigé.

Les résultats et les enseignements de cette thèse devraient permettre de pousser la réflexion sur les conséquences de la dégradation du capital naturel, plus précisément sur le capital humain en ASS. Ils devraient orienter au mieux les politiques publiques afin d'atteindre les ODD 3, 7 et 13 d'ici 2030.

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Chapter 2

Protected areas and fuel choice: the case of Ivorian households

1 Introduction

Côte d'Ivoire, a sub-Saharan African country once renowned for the extent and richness of its tropical forests, has seen its forest cover practically disappear in less than half a century for several reasons. Côte d'Ivoire has the greatest decline in its tropical rainforest (Vancutsem et al., 2021). Since 1990, the tropical rainforest has lost 79% of its surface area and if the rate of deforestation continues, the tropical rainforest will disappear between 2026 and 2029 (Vancutsem et al., 2021). This deforestation can be explained by the implementation of the "plantation economy" (Dao, 2004; Koné et al., 2014), certain agricultural practices such as increasing conversion of forest land to farmland, bush fires (Koné et al., 2014) and the population density. Indeed, according to the World Bank's World Development Indicators, in 2021 Ivorian population density was estimated at 86.40 inhabitants/ km^2 , still higher than the Sub-Saharan African average of 49.43 inhabitants/ km^2 (World Bank Group, 2023). Furthermore, according to the results of the National Forest and Wildlife Inventory (IFFN), the country has a national forest area of 2.97 million hectares, of which 674,500 hectares are protected areas (Timber Trade Portal, 2023).

The availability of energy sources is very useful in meeting people's energy needs for lighting or cooking. In developing countries, and more specifically in Côte d'Ivoire, plant biomass is the primary source of cooking energy. One of the reasons is that biomass is more affordable. The extensive use of forest biomass can also be a driver of deforestation. To alleviate this problem, Côte d'Ivoire introduced an action plan.

As part of the implementation of the ECOWAS Renewable Energy Policy (PERC), Côte d'Ivoire introduced a National Renewable Energy Action Plan (PANER) in 2016 (WHO, 2022). The main objective of the PERC is to increase the share of renewable energies in the region's overall electricity mix to 10% by 2020 and 19% by 2030. The policy focuses primarily on the electricity sector, but also considers other issues including thermal uses in the domestic energy sector and the potential production of biofuels. The aim of the PANER is to contribute to the achievement of the PERC objective through the implementation of specific objectives. The first is to increase access to clean energy such as LPG (Liquified Petroleum Gas) and to reduce the demand for polluting energy, more specifically to reduce the amount of wood energy used. To achieve this, awareness-raising activities on the use of improved stoves and butane gas have been undertaken (Ministère du Pétrole et de l'Energie, 2016). The second is the reduction of polluting emissions (fine particles and greenhouse gases) and the preservation of the forest cover. Indeed, in terms of cooking, biomass energy (firewood, charcoal, vegetable waste) represents a little more than 2/3 of the total final energy consumption of households (Ministère du Pétrole et de l'Energie, 2016). In view of the consumption of wood-energy, the vegetation cover of

Côte d'Ivoire risks disappearing if nothing is done, as the Ivorian forest has gone from 9 million ha in 1965 to 2.8 million ha in 2021 (Ministère du Pétrole et de l'Energie, 2016; TIMBERTRADE, 2022). To achieve this, the PANER aims to increase the share of the population consuming modern alternative cooking fuels such as LPG (Liquified Petroleum Gas) to 90% by 2030 (Ministère du Pétrole et de l'Energie, 2016). This objective is in line with that of the International Energy Agency, whose Africa Energy Outlook 2022 forecasts the elimination of the traditional use of bioenergy for cooking by 2030, thanks to universal access to modern fuels and technologies. Another important specific objective of PANER is to achieve gender equity in terms of cooking fuel use (Ministère du Pétrole et de l'Energie, 2016). Through PANER, Côte d'Ivoire is working to reduce the use of solid fuels such as coal and biomass.

In sub-Saharan Africa, forests are a source of livelihood for poor households living in their vicinity. For example, they find food or firewood there. To combat deforestation and preserve biodiversity, protected areas have been set up. According to the IUCN (International Union for Conservation of Nature), a protected area is *"a clearly defined geographical space, recognised, dedicated and managed, by any effective legal or other means, to ensure the long-term conservation of nature and its associated ecosystem services and cultural values"*. The IUCN classifies protected areas into six categories (Day et al., 2012), with decreasing level of protection. The first category is the "integral nature reserve", which is characterised by strict protection of biodiversity and geological/geomorphological features. Visits, use and human impacts are strictly controlled and limited to ensure that conservation values are protected. The last category is "Managed Natural Resource Protected Areas", which are characterised by management for sustainable use. Previous studies have looked at the impacts of the presence of protected areas and find an effect on deforestation (Andam et al., 2008; Clark et al., 2008), household income (Nepal, 1997; de Sherbinin, 2008; Naidoo et al., 2019) and health (Romagosa et al., 2015; Puhakka et al., 2017; Jiricka-Pürrer et al., 2019; Buckley et al., 2019). Given that the establishment of a protected area helps to combat deforestation, the objective of the study is to find out how the presence of a protected area shapes the cooking fuel choice of households living in the locality.

According to the literature, households' choice of cooking fuel in the event of a change in economic status follows two important hypotheses: Energy ladder hypothesis and Energy stacking hypothesis. In the Energy ladder hypothesis, households replace traditional fuels with modern ones, and this energy transition is motivated by increased income and socio-economic status (Hosier and Dowd, 1987; Van der Kroon et al., 2013). Households may also decide to use several different fuels simultaneously. This is referred to as the fuel stacking or mixing hypothesis (Masera et al., 2000; Heltberg, 2004; Ruiz-Mercado and

Masera, 2015; Choumert-Nkolo et al., 2019). Given that the establishment of protected areas could reduce deforestation and affect the economic status of households in the surrounding area, the aim of the study is to find out whether this would lead to an energy transition to cleaner modern fuels, or to the simultaneous use of traditional and modern fuels by households.

This study stands out in several ways. First, to our knowledge, this is the first to examine the impact of protected areas on the fuel choice of Ivorian households. Second, given the non-random distribution of protected areas, we take into account the characteristics of the sub-prefecture that may influence the location of protected areas. Thirdly, we use a multilevel mixed-effects logistic model that allows to take into account the structure of the data, which in reality are household and sub-prefecture level data. And random effects at the household level are added to the model to take into account certain factors that may affect the household fuel choice. Finally, to answer the research question, we use data from the 2015 Côte d'Ivoire Household Living Standards Survey and the World Database on Protected Areas (WDPA). This study is the first to use these data to investigate the relationship between the presence of protected areas and household cooking fuel choice.

We find the presence of a protected area influences household cooking fuel choice. It increases the likelihood of using purchased biomass compared to clean energy (gas/LPG/butane gas or petroleum-powered appliances)[1]. Furthermore, the impact depends on the type and the protection level of the protected area, and the area of residence. Some factors, such as the characteristics of the household head and the socio-economic status of the household, affect the choice of cooking fuel by households in Côte d'Ivoire.

The rest of the study is organised as follows: the next section presents the literature review. The materials are presented in the third section. The fourth and fifth sections describes respectively the stylized facts and the econometric analysis. Then, the sixth and seventh sections are devoted respectively to the presentation of the robustness checks and the heterogeneity tests. The last section discusses the conclusion and policy implications.

2 Background

The following sections look at the different impacts of protected areas, with a particular focus on health effects, and the use of forests as a source of household fuel.

[1] We consider clean fuels to be those that are less harmful to household health

2.1 Socio-economic impact of forest protection

Forests provide important ecosystem services (Brandon, 2014). More specifically tropical forests have a major influence on weather patterns, freshwater, natural disasters, biodiviersity, food and human health (Brandon, 2014). Forests contribute significantly to the livelihoods of the poorest households (Heubach et al., 2011) and also enable carbon sequestration (Jindal et al., 2008).

The establishment of protected areas helps to preserve forests. In addition to their role in natural water purification in wetlands and carbon sequestration in forests, protected areas are an important tool in the fight against deforestation. The impact of forest conservation policies on deforestation remains controversial (Brandt et al., 2016; Karsenty et al., 2017; Brandt et al., 2018). Several studies deal with the effect of protected areas on deforestation (Andam et al., 2008; Clark et al., 2008; Kere et al., 2017). These authors find that protected areas help to combat deforestation. Indeed, the fact that certain parts of the forest are protected discourages the population from deforesting these parts on pain of paying a fine. It is in this sense that Andam et al. (2008) show that between 1960-1970, 10% of the protected forests would have been deforested if they were not protected in Costa Rica. Clark et al. (2008) add that the establishment of protected areas makes it possible to fight deforestation but it is not known to what extent this leads to a displacement of deforestation. To add protected areas helped slow deforestation in the Brazilian Amazon between 2005 and 2009 (Kere et al., 2017) .

Since the forest is multifunctional, protected areas have the potential to affect many other things. A number of studies have looked at the various socio-economic impacts of protected areas. Some scholars find protected areas have an economic value because it improves the mental health and well-being of the population. Using the quality-adjusted life years (QALY), Buckley et al. (2019) show that this value amounts to 6,000 billion dollars per year in Australia. In the same vein, Koss et al. (2010) find a positive effect of protected areas on the mental health of volunteers who care for them. Visitors report protected areas have a positive effect on their psychological, physical and social health (Jiricka-Pürrer et al., 2019; Puhakka et al., 2017; Terraube et al., 2017; Romagosa et al., 2015).

In addition, another group of studies agree protected areas affect the health of populations through improved nutrition. Aswani and Furusawa (2007) supports this idea by comparing two villages, one with a marine protected area and one without. The results show that the populations of the village with a marine protected area had a higher energy and protein intake than those of the other village without a protected area.

Also, some authors give protected areas the power to generate income for local populations, especially in sub-Saharan Africa. It is in this sense Heubach et al. (2011) prove non-timber forest products are an essential means of subsistence for rural households in Benin. de Sherbinin (2008) looks at the relationship between poverty and living near a park. By approximating poverty by the infant mortality rate, the results show an uncertain causal relationship between poverty and proximity to a protected area. In contrast, Naidoo et al. (2019) find a relationship between proximity to a protected area, poverty and general well-being. Indeed, households in the vicinity are richer and children do not show stunted growth compared to similar households that are far from the protected area. The authors explain this by tourism activities that generate income. This income could be used for medical consultations and the purchase of medicines. Also, wildlife conservation promotes the multiplication of animals that households can later sell. Furthermore, the presence of a protected area could encourage the construction of infrastructure, especially roads, and this facilitates the transport of the sick (Naidoo et al., 2019).

Although the creation of protected areas helps to reduce deforestation, they have other impacts too. This literature show that protected areas impact on people's health through their positive psychological, physical and nutritional effects. It also constitutes a source of income for some individuals and thus allow them to have the necessary resources to treat themselves. In this study we test the effect of the presence of protected areas on the household cooking fuel choice. On the one hand, the presence of a protected area could increase the opportunity cost of wood, but on the other, if proximity to the protected area could increase income-generating activities, this could stimulate demand for fuel. We would expect this to change their choice of cooking fuel.

2.2 The forest as fuel

The poor are dependent on natural resources such as forests, which provide them with goods and services: food resources, but also energy resources such as firewood (Sukhdev, 2009). Moreover, tropical developing countries are home to many endangered and threatened species. As a result, many of the newer protected areas are located in poor areas of the world (Howlader and Ando, 2020). Many poor households live around protected areas. These households are highly dependent on forest resources, for income or subsistence. According to Velho et al. (2019) the increase in income of households living around protected areas in India, does not necessarily affect the use of collected wood as cooking fuel. It is in this same vein that Khanwilkar et al. (2021) finds that living near the forest slows down the adoption of LPG as a fuel by households in India. Also according to these authors, 90% of households using LPG continue to use firewood as fuel. The adoption of LPG does not necessarily encourage households to abandon the use of wood for cooking.

Howlader and Ando (2020) look at the impact of protected areas on the welfare of households living in their vicinity in Nepal. The results show that the establishment of protected areas reduces timber collection by 20-40% compared to the period when there was no protected area. According to Pattanayak et al. (2004), the increased cost of accessing the forest could reduce people's dependence on collecting fuelwood from the forests. In addition, there are other factors that contribute to the decline in wood collection. These include wealth, use of alternative fuels, ownership of paraffin stoves, construction of primary schools and roads.

From previous studies it can be seen the presence of a protected area could reduce (Pattanayak et al., 2004; Howlader and Ando, 2020) or not the use of collected fuelwood (Velho et al., 2019). In this study, we examine the extent to which the presence of a protected area would change the cooking fuel choice of households living in the relevant sub-prefectures in Côte d'Ivoire. An important contribution of this paper is to fill the gap that exists in the literature regarding the link between protected area, forest and fuel choice in Africa. The following section look at the data used to do the analysis.

3 Materials

We will analyse the effects of the presence of protected areas on household cooking fuel choice using data from the 2015 Household Level Survey and an econometric method.

3.1 Data

The data used in this study come from different sources. The unit of observation is the household, whose main characteristics are given by the 2015 Household living standards survey. The main purpose of the Côte d'Ivoire household living standards survey is to provide the information needed to improve planning and evaluation of economic and social policies. The survey provides information on household composition, education, employment and health, among other things. It was conducted by the National Institute of Statistics (INS) of Côte d'Ivoire. The sampling frame used to draw the sample is the 2014 General Census of Population and Housing. The sampling is based on a two-stage draw. The first stage consists of a proportional allocation of the Enumeration Areas (EAs). The second is a systematic drawing of 12 households per enumeration area. The total sample obtained consists of 12,900 African households residing in Côte d'Ivoire (INS, 2023). This study is based on a sample of 12899 households.

The information on protected areas comes from the World Database on Protected Areas (WDPA) (UNEP-WCMC and IUCN, 2021) which is a joint project of the United Nations Environment Programme (UNEP) and the International Union for Conservation of Nature (IUCN). The database includes all terrestrial and marine protected areas (Chape et al., 2005). For the purposes of this study, we are interested in terrestrial protected areas. In the database, we identify several types of protected area such as classified forest, national park, nature reserve and partial nature reserve. To obtain data on protected areas by sub-prefecture, we use the QGIS software, which has enabled us to obtain the surface area of protected areas present in the sub-prefectures.

3.2 Outcomes variables

In the study, four indicator variables are used as dependent variables. It reveals the extent to which the presence of a protected area shapes the household's energy transition, especially as regards cooking fuel. These variables are constructed from the question *"O17: Main cooking fuel sources"*. The possible answer modalities are: *"charcoal, purchased wood, collected wood, gas, electricity, oil, not applicable"*. The household was asked to choose the first three sources of fuel used. We are only interested in the first fuel source to construct the four indicators used as dependent variables.

The first indicator "Biomass/no biomass" is 1 when the household uses purchased or collected biomass (wood or charcoal) and the value is 0 if the household uses clean energy (gas/LPG/butane gas or petroleum-powered appliances). This dependent variable allows us to see how the presence of a protected area influences the choice of fuel, regardless of the type of biomass supply used as fuel.

Then, the second indicator "Biomass collected/ purchased" is equal to 1 when the household uses collected biomass (collected wood) and 0 when the household uses purchased biomass (charcoal or purchased wood). The objective of this indicator is to provide information on the extent to which the presence of a protected area could encourage the household to choose between collected and purchased biomass. The use of this outcome variable is justified by the fact the protected area is sometimes considered a source of wood supply for some households, especially in rural areas.

The third indicator "Biomass collected/no biomass" is 1 when the household uses collected biomass and 0 if it uses clean energy (gas/LPG/butane gas or petroleum-powered appliances). The purpose of this variable is to show the extent to which the establishment of a protected area could force the household to choose between collected biomass and clean energy.

The fourth indicator "Biomass purchased/no biomass" is 1 when the household uses purchased biomass and 0 if it uses clean energy (gas/LPG/butane gas or petroleum-powered appliances). The objective is to see how the presence of a protected area might influence the household's transition from purchased biomass to clean energy.

3.3 Interest variable

Using QGIS software we obtain the protected area surface by sub-prefecture. On the Figure 2.1, it can be seen there is a great difference between protected areas in terms of surface area. The very large protected areas are more concentrated in the North-East and South-West of the country. In the North-East, more precisely in the Savanes and Zanzan districts, is the Comoé National Park with a surface area of 1,149,150 hectares. In the south-western zone, there are large national parks such as the Mont Péko National Park, the Tai National Park, the Mont Sangbé National Park and the Azagny National Park. These parks were created in the 1960s, 1970s and 1980s.

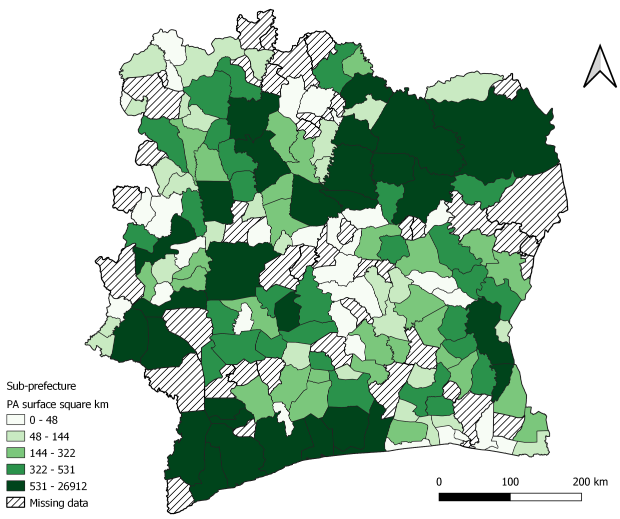

Figure 2.1: Size of protected areas by sub-prefecture
Source : Author's construction using the World Database on Protected Areas

3.4 Covariates

In order to better take into account the level of household wealth, we construct a wealth index. Indeed, the construction of the wealth index is very important because it allows us to measure the economic status of households. It is created by aggregating information on housing, physical capital and assets held by the household. Thus, the value of the index provides information on the living conditions of households that affect the well-being of individuals. The index is created through multiple component analysis. The synthetic index obtained is then normalised and thus lies between 0 and 1 with an average of 0.25 for urban households and 0.12 for rural households (Table A1). The higher the level of wealth, the closer the index will be to 1. The variables used and their definitions are found in Table B1 in Annex B.

The size of the household influences the household's choice of fuel (Bofah et al., 2022; Twumasi et al., 2021). Indeed, the larger the household, the more fuel expenses increase because a large quantity of food must be cooked. Under these conditions, a low-income household would have to choose a cheaper fuel, i.e. biomass. The average household size in the sample is about 4 members with a maximum size of 26 members in urban area and 36 members in rural area (Table A1).

The household head age is a very important characteristic that could affect the consumption choices of household members. Through an empirical study on the determinants of the transition to cleaner cooking energy in Ghana, Bofah et al. (2022) find that youth-headed households have a low probability of using dirty energy compared to elderly-headed households in Ghana. The authors explain this by the decrease in income of the elderly head of household. As a result, the household chooses cheaper fuels that unfortunately pollute a lot. To add, the author's result could be explain by the fact that these elderly-headed households do not have information about the harmful effects of using dirty energy.

The gender of the head of household is an important determinant in the choice of cooking fuel. Bofah et al. (2022) shows that female-headed households are about 1.3 times more likely to use dirty cooking energy (i.e. wood and charcoal). Indeed, female-headed households are likely to be poorer than male-headed households (Javed and Asif, 2011). This could be explained by the fact these women do not have financial support from a spouse either because they are single, divorced or widowed.

Furthermore, the level of education and the type of occupation of the household head are also essential factors in the choice of cooking energy. Indeed, Bofah et al. (2022); Twumasi et al. (2021) show that the choice of fuel is influenced by the level of education of the head of household and non-agricultural employment. Having a high level of education would enable the household head to better understand the adverse effects of biomass use on the health of household members. The type of occupation of the household head informs about the economic conditions of the household.

In addition to the information that allows us to understand the socio-economic status of households, which strongly influences household fuel choice, we need to take into account the characteristics of the sub-prefecture. To this end, we include rainfall, temperature and the number of mammals and birds in the analysis. This information could influence the establishment of a protected area in an area.

The following section provides an understanding of the correlations between the presence of protected areas and household fuel choice.

4 Stylized facts

Biomass is widely used in developing countries. This is the case in Côte d'Ivoire. Figure 2.2 shows the main source of cooking fuel used by households. It can be seen that around 57% of households use collected biomass for cooking. Also, a significant proportion (14.95 %) of households use charcoal. Just a small proportion (4.29%) use purchased wood. This graph 2.2 shows that around 76.1% of households use plant biomass for cooking. One might imagine that this enormous use of biomass would not be without effect on Côte d'Ivoire's forest cover.

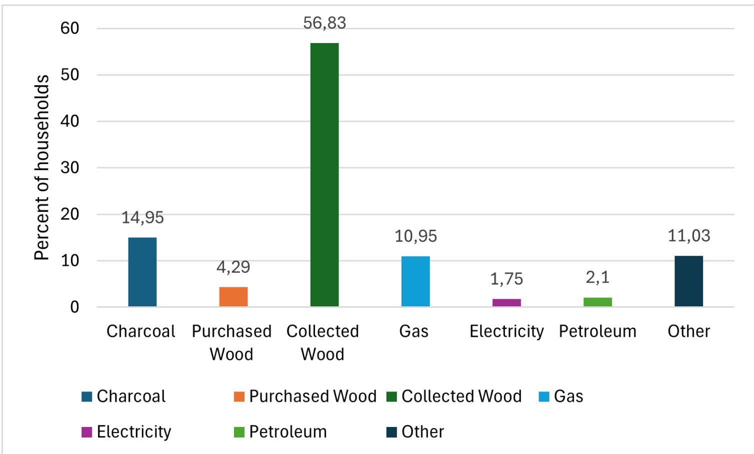

Figure 2.2: Primary source of cooking fuel used by household
Source: Author's construction using the 2015 Côte d'Ivoire household living standards survey

In terms of modern cooking fuels, only 10.95% (graph 2.2) of households use gas. This proportion is set to rise, as the Ivorian government plans to have 90% of the population using alternative modern cooking fuels (e.g. LPG) by 2030, thanks to the implementation of the PANER program.

Before the econometric analysis, it is important to look for a possible correlation between the use of biomass for cooking and the presence of protected areas. The Figure 2.3 is in line with this idea. It shows that 52.58% of households in the sample that use biomass (firewood and charcoal) live in sub-prefectures where there is a protected area.

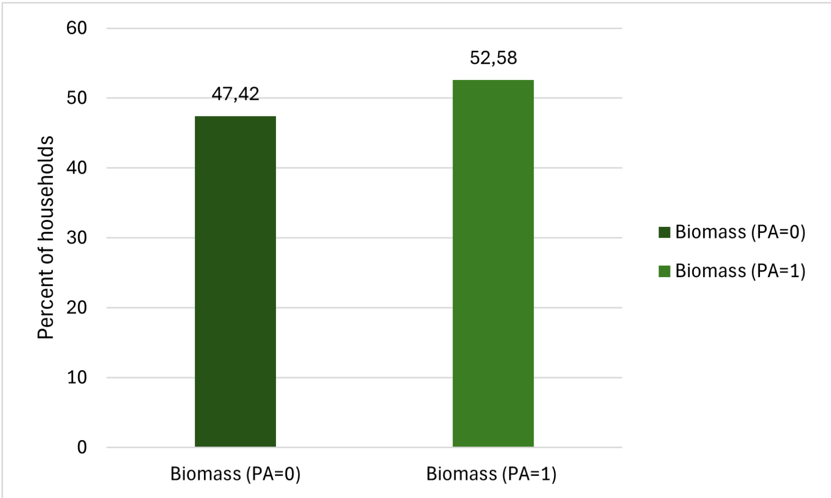

Figure 2.3: Households using biomass for fuel by presence of protected areas
Source: Author's construction using the 2015 Côte d'Ivoire household living standards survey

Furthermore, the presence of a protected area could alter households' fuel choices in several ways. This is the logic behind the Figure 2.4. The Figure on the left shows that 73.8% of households that use purchased biomass (fuelwood or charcoal) are located in sub-prefectures where there is a protected area. In view of these figures, it is tempting to say that the presence of a protected area would discourage households from using collected biomass, and more specifically collected wood. In other words, the presence of a protected area could mean that it is forbidden to harvest timber if it is an integral protected area. This restricts the geographical possibilities for collecting wood. This situation would force some households to buy biomass instead of collecting it.

In order to deepen the analysis, we focus on households that use purchased charcoal. According to the data, of households using purchased biomass and living in sub-prefectures with PAs, 75.52% use charcoal. In addition, among households using purchased biomass and living in sub-prefectures without PAs, 72.62% use charcoal. Furthermore, the Figure on the right (graph 2.4) shows around 76% of charcoal-using households live in sub-prefectures with a PA. The last graph in Figure 2.4 focuses solely on households that use

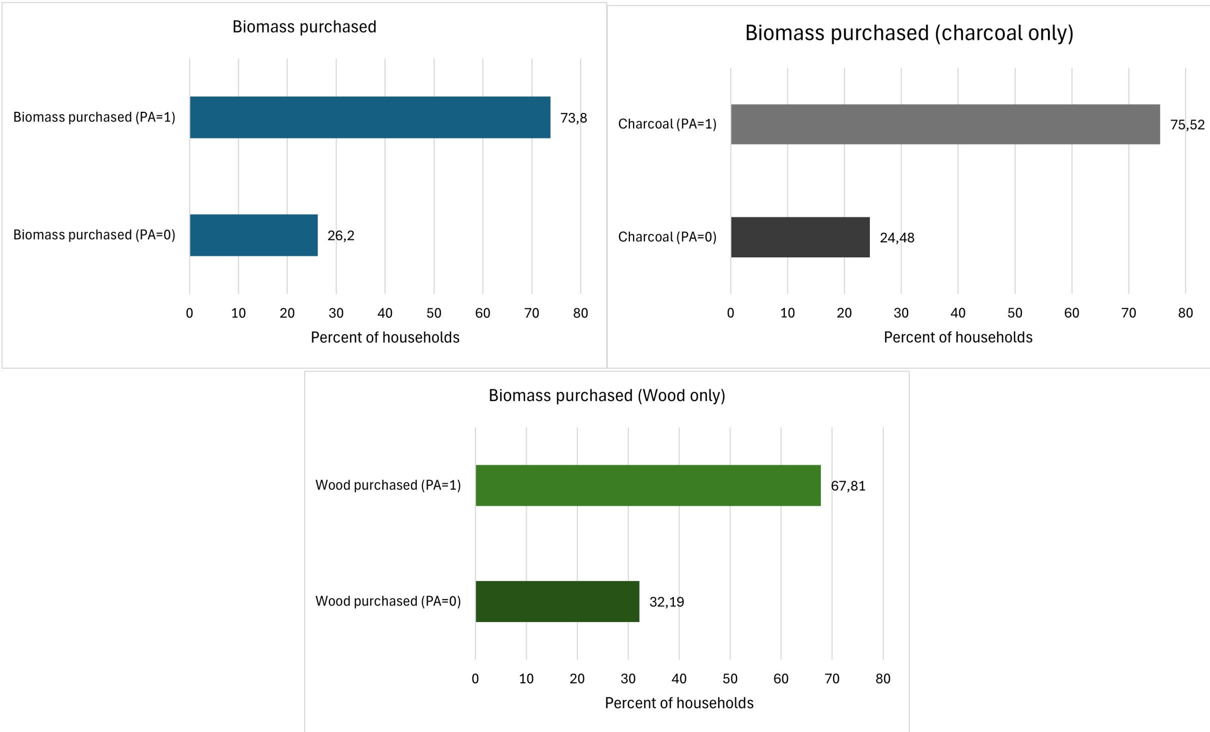

Figure 2.4: Households using purchased biomass according to protected area presence
Source: Author's construction using the 2015 Côte d'Ivoire household living standards survey

purchased wood. It can be seen that around 68% of households that use purchased wood for cooking live in areas where there is a protected area. From this graph 2.4, one might imagine that there is a positive correlation between the presence of PAs and the use of purchased biomass, and more specifically charcoal.

Figure 2.5 looks at households that use collected biomass (collected wood). The Figure shows around 55% of these households live in sub-prefectures without a protected area. This finding could lead us to believe that there is a negative correlation between the presence of a protected area and the use of collected fuelwood.

Several types of fuels can be used. Some of these fuels are less harmful to the health of households: we consider this as clean energy in the study. Indeed, in the data we notice that some households use clean energy as cooking fuel. This type of fuel is less polluting but expensive for poor households. According to the sample, 1638 Ivorian households use clean fuels (gas or electricity or petroleum-powered appliances) for cooking. A large majority of these households (81%) live in sub-prefectures with a protected area (graph 2.6). From this figure, one might imagine that there is a positive co-evolution between the presence of a protected area and the use of clean energy for cooking.

We looked at the level of wealth of the households in the sample through the wealth

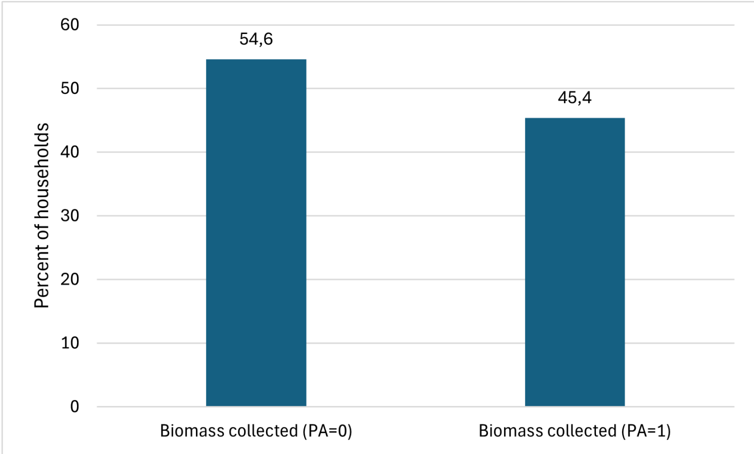

Figure 2.5: Households using collected biomass for fuel by presence of protected areas
Source: Author's construction using the 2015 Côte d'Ivoire household living standards survey

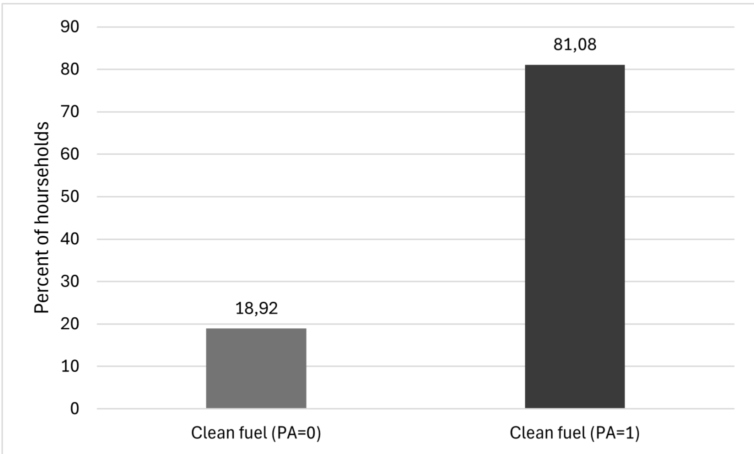

Figure 2.6: Households using clean fuel (gas/electricity/petroleum-powered appliances) by presence of protected areas
Source: Author's construction using the 2015 Côte d'Ivoire household living standards survey

index. The index values show that households using clean energy (gas/LPG/butane gas or petroleum-powered appliances) are on average wealthier (0.4) than those using biomass (0.17). In addition, households living in sub-prefectures where there is a protected area are on average slightly richer (0.23) than households living in sub-prefectures without a protected area (0.16).

The remainder of the study will focus on econometric analysis to verify the stylized facts that have just been discovered.

5 Econometric analysis

This section describes the endogeneity problem, the econometric model and the main results.

5.1 Endogeneity problem

The distribution of protected areas is non-random (Joppa and Pfaff, 2009; Sims, 2010; Amin et al., 2015). Their location is chosen according to certain characteristics of the area. These protected areas are generally located on land characterised by low soil fertility, the presence of slopes and poor accessibility: land that is not favourable for agriculture (Albers et al., 2006). Failure to take these characteristics into account could lead to an omitted variable bias that will subsequently lead to an endogeneity bias in the analysis. This endogeneity bias could lead to a bias in the estimation of the impact of the presence of protected areas.

Protected areas are located in areas with low agricultural profitability, which could in turn affect the income of economic agents and their choice of location and fuels. To resolve the endogeneity bias we take into account certain characteristics of the sub-prefectures such as rainfall, temperature and biodiversity. These characteristics are crucial in the establishment of protected areas. Data on temperature and rainfall are taken from NASA databases. Biodiversity data is from the Schipper et al. (2020) database. All these data are satellite data extracted using QGIS software.

5.2 Econometric model

In this study a dichotomous model is used where the explained variable has two modalities (0 and 1). We can choose between two types of dichotomous models: probit model and logit model. Difference between the two models lies in the mathematical law of the distribution function used. Logistic model uses the distribution function of the logistic distribution while probit model uses the distribution function of the reduced centred normal distribution. These two models provide fairly similar results because of the similarities between logistic and the reduced centred normal distribution. However logit model has advantages in the interpretation of marginal effects. Furthermore, data is at 2 levels: sub-prefecture and household. Indeed, beyond the characteristics of each household, several households live in common sub-prefectures. Also, it is important to take into account the "context effects" in order to estimate the impact of the variables without bias (Kere et al., 2017). Therefore, for the econometric analysis, we choose the multilevel mixed-effects logit model because it allows to take into account the hierarchical nature of the data and to use random effects. So we add random effects at the household level as this allows to take into account the influence of certain factors that affect household fuel choice. These could include the type of food cooked, cultural characteristics, etc.

The likelihood-ratio test is computed to evaluate the goodness of fit of the chosen model. The test is done between a model with the control variables (unconstrained model) and another model without the control variables (constrained model). The P-value of the test results are in the results tables.

5.3 Baseline results

An increase in the cost of access to the forest through the establishment of a protected area could have an impact on the cooking fuel use patterns of households living near these protected areas. In Table 2.1 (column 1), we find that the presence of a protected area in a sub-prefecture increases the probability of a household using biomass compared to clean fuel by 2.58 percentage points. More precisely, in column 4, the presence of a protected area has a positive marginal effect of 6.78 percentage points on the likelihood of using purchased biomass compared to clean fuel. These two results show that the presence of a protected area increases the probability of using biomass purchased as cooking fuel. In view of these results, one might think that the presence of a protected area has no effect on wood collection, but it positively influences the use of purchased biomass (charcoal and wood) compared to clean fuel by the households.

Furthermore, the characteristics of the household head affect the fuel choice of the household. Firstly, the results show that the household head age is a relevant factor in the household's choice of fuel (Table 2.1). Indeed, an increase in the age of the head of household has a positive marginal effect (0.118 percentage points to 0.208 percentage points) on household fuel choice (column 1 to 4 Table 2.1). This can be explained by the drop in income of elderly heads of household, and this drop in income encourages them to use dirty fuels which are more accessible financially. Also, this result can mean these elderly-headed households do not have information about the harmful effects of using dirty energy.

Also, the fact the household head is a man increases the likelihood of using the biomass collected by 6.92 percentage points (Table 2.1 column 2). This can be due to the fact a male household head can participate in the collection of wood.

The level of education of the household head is an important factor in the household's choice of cooking fuel. Having secondary and higher education has a marginal negative effect on the likelihood of the household using biomass for cooking (Columns 1, 2, 3 and 4 Table 2.1). A plausibe explanation is that having a high level of education helps to understand the negative health effects of using biomass as fuel.

Table 2.1: Baseline results

	Biomass/ no biomass	Biomas collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA presence	0.0258**	-0.00193	-0.000960	0.0678***
	(2.05)	(-0.12)	(-0.08)	(2.61)
Head age	0.00142***	0.00169***	0.00118***	0.00208***
	(5.10)	(5.28)	(4.60)	(3.58)
Head gender (male)	0.00375	0.0692***	0.00646	-0.00729
	(0.46)	(6.45)	(0.81)	(-0.45)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0132	0.00527	-0.000625	-0.0238
	(-1.30)	(0.40)	(-0.06)	(-1.15)
Secondary education (head)	-0.0218**	-0.0482***	-0.0113	-0.0259
	(-2.37)	(-3.58)	(-1.22)	(-1.43)
Higher education (head)	-0.106***	-0.0217	-0.115***	-0.174***
	(-5.42)	(-0.59)	(-4.50)	(-5.65)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.101***	-0.308***	-0.155***	0.0964**
	(-6.81)	(-9.95)	(-7.92)	(2.55)
Other occupation (head)	-0.0929***	-0.291***	-0.133***	0.111***
	(-8.72)	(-24.68)	(-12.43)	(3.22)
Wealth index	-0.676***	-1.558***	-0.821***	-0.901***
	(-26.72)	(-35.03)	(-28.98)	(-17.67)
Household size	0.0139***	0.00656***	0.0108***	0.0244***
	(8.01)	(3.47)	(6.61)	(7.27)
Rainfall	-0.155***	-0.131***	-0.141***	-0.238***
	(-12.15)	(-7.66)	(-11.35)	(-9.05)
Temperature	0.0316***	0.000728	0.0222***	0.0667***
	(11.62)	(0.23)	(9.24)	(11.12)
Mammals & birds	0.178***	0.105***	0.160***	0.284***
	(22.06)	(7.18)	(18.84)	(18.07)
Observations	7209	5751	5207	3460
LR test p value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses,
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Robust standard errors

In addition, the type of occupation of the head of household influences the household's choice of cooking fuel. The fact that the household head is a "white collar" worker or "other occupation" worker has a marginal negative effect (10.1 percentage points and 9.29 percentage points respectively) on the likelihood of using biomass compared to a farmer household head (Column 1 Table 2.1). Going into more detail, it can be seen that the effect size is larger when it comes to the use of collected biomass compared to purchased biomass or compared to clean fuel (Columns 2, 3 Table 2.1). However, the effect changes sign when it comes to the likelihood of using purchased biomass (Column 4 Table 2.1). These results show that the fact that the household head is not a farmer reduces the likelihood of using collected biomass. This result seems to be consistent with the idea that a farmer may have access to wood when he goes to the field.

The level of wealth very significantly decreases the likelihood of using biomass as a cooking fuel (Table 2.1). This result shows that one of the essential determinants of cooking fuel choice is the level of household income. Indeed, a poor household will be forced to use biomass because it is the cheapest fuel the household can afford. A rich household, on the other hand, has a wide range of fuels it can use. As a result, the rich household would tend to switch to cleaner fuels. This result is in line with previous studies that found that poverty is one of the main factors driving households to use biomass (Pattanayak et al., 2004; Velho et al., 2019).

The size of the household has a great influence on cooking fuel choice (Table 2.1). Indeed, a large household size could mean a large amount of food to cook and therefore a large amount of fuel to use for cooking. In this situation, a household would have an incentive to use biomass which is cheaper than clean fuels and therefore more affordable. Here again, we return to the household's socio-economic status factor. The results show that household size increases the likelihood of biomass use by 0.656 percentage points to 2.44 percentage points.

Furthermore, the characteristics of the sub-prefecture play an important role in the location of a protected area and could influence the cooking fuel choice of households living there. In Table 2.1, we can see that the level of rainfall marginally decreases the likelihood of using biomass as fuel. This result is explained by the fact biomass is not usable when it is wet. On the other hand, temperature has a marginally positive effect on the likelihood of using collected or purchased biomass compared to clean fuel (columns 1, 3 and 4 Table 2.1). Indeed, a rise in temperature as opposed to rain allows the biomass to dry better and it becomes even easier to use for fire. In addition, the mammal and bird stock in the sub-prefecture has a marginal positive effect (10.5 percentage points to 28.4 percentage points) on the likelihood of biomass use. This could be explained by the fact more biodiversity stock would mean more forest area, and when forest is accessible, it encourages the household to use biomass which becomes more accessible at lower cost.

The next section focuses on the robustness checks of the previous results.

6 Robustness checks

We test the robustness of the baseline results using Generalized Structural Equation Modeling (GSEM) (Table 2.2).

GSEM is used to examine the direct and indirect linear relationships of the variables in the model, taking into account the binary response variable. The results obtained are in line with the baseline results and show that the presence of a protected area increases

Table 2.2: Generalized Structural Equation Modeling

	Biomass/ no biomass	Biomas collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA presence	0.288**	-0.0152	-0.0147	0.399***
	(2.04)	(-0.12)	(-0.08)	(2.60)
Head age	0.0159***	0.0133***	0.0182***	0.0122***
	(5.08)	(5.21)	(4.61)	(3.56)
Head gender (male)	0.0417	0.544***	0.0991	-0.0429
	(0.46)	(6.32)	(0.81)	(-0.45)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.146	0.0413	-0.00932	-0.137
	(-1.31)	(0.40)	(-0.06)	(-1.15)
Secondary education (head)	-0.237**	-0.368***	-0.166	-0.149
	(-2.41)	(-3.65)	(-1.24)	(-1.44)
Higher education (head)	-1.025***	-0.168	-1.448***	-0.969***
	(-6.09)	(-0.60)	(-5.32)	(-5.75)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-1.202***	-2.280***	-2.159***	0.558**
	(-6.86)	(-12.01)	(-9.56)	(2.53)
Other occupation (head)	-1.122***	-2.183***	-1.921***	0.643***
	(-7.69)	(-20.56)	(-11.48)	(3.22)
Wealth index	-7.534***	-12.26***	-12.60***	-5.304***
	(-22.87)	(-24.13)	(-22.37)	(-15.32)
Household size	0.155***	0.0517***	0.166***	0.144***
	(7.87)	(3.46)	(6.49)	(7.10)
Rainfall	-1.729***	-1.033***	-2.165***	-1.401***
	(-11.32)	(-7.54)	(-10.27)	(-8.68)
Temperature	0.352***	0.00573	0.341***	0.392***
	(11.76)	(0.23)	(9.50)	(10.81)
Mammals & birds	1.982***	0.825***	2.451***	1.675***
	(18.72)	(7.07)	(15.75)	(15.65)
Observations	7209	5751	5207	3460
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Robust standard errors

the likelihood of purchased biomass use compared to clean fuel.

7 Heterogeneity

This section looks at the heterogeneity of the effect according to the level of development of the sub-prefecture, the type and surface of protected area.

7.1 Effect according to the level of development of the sub-prefecture

The influence of the presence of a protected area could vary depending on several factors. First, we look at how the influence of the presence of a protected area affects households' fuel choices according to the level of development of the sub-prefecture. In the Table C1, we use the level of nightlight to approximate the level of development of the area. The results show living in a sub-prefecture with a nightlight level below the median increases the likelihood of biomass use by 3.09 percentage points and of biomass collected by 2.28 percentage points (columns 4 and 6 Table C1). Then, still with a view to taking into account the level of development, in Table C2, we are interested in the heterogeneity of the effect depending on whether the sub-prefecture is urban or rural. Indeed, we assume that the more developed the area, the more households have access to clean energy compared to less developed areas. The results in Table C2 (column 2) show the presence of a protected area in an urban area increases the probability of using purchased biomass by 8.01 percentage points compared to clean energy. However, the effect is insignificant when it is a protected area in a rural area. This could be explained by the fact that in urban areas households have few opportunities to collect biomass as they do in rural areas, and they may not have the time to do so because of other activities. In addition, the wealth index constructed shows that urban households are wealthier than rural ones. As a result, they may have the financial means to buy biomass.

7.2 Effect depending on the size of the protected area

The effect of the protected area on the choice of fuel could depend on its size, since size can affect the quality of management and thus the effectiveness of the protected area. A relatively small protected area might be easier to manage because it would require fewer human resources, for example, than a larger protected area. To this end, we divide the surface of protected areas into quartiles and the results can be found in Tables C3, C4, C5 and C6. We can see when the protected area belongs to the first quartile this affects households' choice of fuel, as they prefer collected biomass to purchased biomass or clean energy (columns 2 and 4 in Table C3). The presence of a protected area increases the probability of using collected biomass by 3 percentage points and 4 percentage points. Furthermore, a protected area with a surface in the second quartile increases the probability of using the biomass collected by 2 percentage points compared to clean fuel (columns 1 and 3 Table C4). On the other hand, the presence of a fairly large protected area (third quartile) reduces the probability of using collected biomass (by 5 percentage points and 7 percentage points) compared to purchased biomass and clean fuel (columns 1, 2 and 3 Table C5). Very large protected areas positively affect the use of collected biomass by 3 and 6 percentage points (columns 2 and 3 Table C6).

These results show the importance of taking into account the size of the protected area in understanding the influence of the protected area on households' choice of cooking fuels. Small/medium and very large protected areas have a positive effect on the probability of using the biomass collected, while the effect becomes negative in the case of large protected areas (third quartile). These results could be explained by the type of protected area that makes up each size group. We start with the second quartile because we have no information on the type of protected areas in the first quartile. Of the medium-sized protected areas (second quartile), 94.3% are classified forests, protected areas in the third quartile are made up of 61% classified forests and 38% parks, and protected areas in the last quartile are made up of 85% classified forests and 14% parks. These figures show the positive effect observed with the first, second and last quartile protected areas is due to the presence of a large proportion of classified forests and a small proportion of parks. A plausible explanation would be that a classified forest is more likely to be exploited than a park.

7.3 Effect depending on the type of the protected area

This part of the heterogeneity study looks at the effect of the presence of the protected area according to the type of protected area. The results in Table C7 show that the fact the protected area is a classified forest has no effect on households' choice of cooking fuel.

Furthermore, the fact that the protected area is a park decreases the likelihood of using collected biomass compared to purchased biomass by 9.82 percentage points. The presence of this type of protected area also decreases the likelihood of using collected biomass compared to clean energy by 5.01 percentage points (columns 2 and 3 Table C8). The park decreases the likelihood of use of collected biomass may be because it is more protected and its presence decrease the geographical possibilities of wood collection.

In the Table C9 (columns 1, 3 and 4), it can be seen the fact that the protected area is a nature reserve increases the likelihood of using biomass (20.8 percentage points), collected biomass (18.7 percentage points) and purchased biomass (41.6 percentage points) compared to clean energy.

The Table C10 looks at the heterogeneity of effect depending on whether the protected area is a national or international protected area. The terms "National" and "International" refer to the type of convention under which the protected area was established. Thus, the "National" protected area is derived from a national convention, whereas the "International" protected area is derived from an international convention. For example, a UNESCO World Heritage site would be an "International" protected area. Also, given that households might know the status of the protected area, we might expect a different impact depending on whether it's a "national" or "international" protected area.

Table C10 show the presence of a "National" protected area increases the likelihood of using biomass (2.68 percentage points) and purchased biomass (6.76 percentage points) compared to clean energy (columns 1 and 4). In contrast, the fact that the protected area is of the "International" type has a marginally low significant effect on the likelihood of using purchased biomass compared to clean energy (column 8). These nil or low significant results could be explained by the fact that the "International" type protected areas are very few compared to the "National" type.

7.4 Effect according to the level of protection of the protected area

Since the results obtained with the type of protected area do not allow us to clearly understand which characteristic of the protected area would reduce the use of biomass, in this section we study the effect according to the level of protection of the protected area. To do this, we create an "integral protected area" indicator, which is 1 if the protected area is characterised by strict protection for the conservation of its resources and 0 if the protected area's resources are used sustainably. We therefore consider nature reserves and parks to be integral protected areas and classified forests to be sustainably managed protected areas. More precisely, the "integral protected area" correspond to IUCN categories I and II.

The results in Table C11 show the fact the protected area is integral reduces the risk of biomass use (Columns 1, 2, 3 and 4 Table C11). Integral protected areas encourage the use of clean energy (gas). In fact, when the protected area is integral, this reduces the geographical possibilities of access to plant biomass. As a result, households cannot collect biomass directly or buy it because biomass sellers do not also have access to the forest. This result shows that the degree of protection of the protected area is very important.

The Ivorian government could therefore be advised to set up integral protected areas that promote not only forest protection but also the use of clean cooking energy by households.

8 Conclusion

The establishment of protected areas to combat deforestation could also affect the fuel choice of Ivorian households, which are highly dependent on plant biomass for cooking. The aim of this study is to test this hypothesis. Using a multilevel mixed-effect model, data from the 2015 household living standards survey and World Database on Protected Areas, the results show the presence of a protected area influences household cooking fuel choice. It increases the likelihood of using purchased biomass compared to clean energy. Furthermore, the impact depends on the type and level of protection of the protected area, and the area of residence. Some factors, such as the characteristics of the household head and the socio-economic status of the household, affect the choice of cooking fuel by households in Côte d'Ivoire.

In terms of economic policy, Ivorian public decision-makers should prioritize the establishment of integral protected areas that promote not only forest protection but also the use of clean energy for cooking. Another recommendation concerns the implementation of policies aimed at strengthening the management of protected areas. These include policies to monitor protected areas so that their presence can help achieve the objectives set. The country could also put in place policies to facilitate access to clean energy. In addition, the population needs to be made aware of the harmful effects of plant biomass use on health. This would help reduce the use of biomass.

This study has limitations. The main limitation is the unavailability of data. We do not have information on the precise location of households. This type of information would allow to better target households living near protected areas based on a certain distance. We hope future surveys will provide this information. Future research would be to compare households that are close to the protected area with those that are not, in terms of their choice of cooking fuel. This would reveal how the choice of cooking fuel varies according to distance from the protected area.

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Appendices

A Descriptive statistics

Table A1: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Urban Households					
Fuel biomass / no bimass	5,087	.7179084	.4500619	0	1
Fuel collected / purchased	3,652	.4463308	.4971793	0	1
Fuel collected / no biomass	3,065	.5318108	.4990685	0	1
Fuel purchased / no biomass	3,457	.5849002	.4928105	0	1
Protected area presence	5,784	.700899	.4579037	0	1
Head age	5,583	40.60147	14.36152	15	120
Head gender	5,784	.7679806	.4221578	0	1
Head education	5,712	.947479	1.041449	0	3
Head occupation	5,784	1.515733	.7627603	0	2
Wealth index	5,784	.2548042	.1587832	0	.9911834
Household size	5,784	3.65612	2.478579	1	26
Rainfall	4,703	3.6193	.6366527	1.224417	5.102239
Temperature	4,703	28.72951	1.344109	26.22738	33.06827
Mammals & birds	4,703	8.526423	.8567235	5.851593	10.32386
Rural households					
Fuel biomass / no bimass	6,389	.9640006	.1863031	0	1
Fuel collected / purchased	6,159	.9254749	.2626448	0	1
Fuel collected / no biomass	5,93	.9612142	.1931004	0	1
Fuel purchased / no biomass	689	.6661829	.4719179	0	1
Protected area presence	7,115	.4559382	.4980898	0	1
Head age	6,966	41.70571	14.99268	15	105
Head gender	7,115	.8326072	.3733525	0	1
Head education	7,085	.4780522	.7716238	0	3
Head occupation	7,115	.8756149	.9758771	0	2
Wealth index	7,115	.1175171	.0814123	0	.8784604
Household size	7,115	3.722839	2.689577	1	36
Rainfall	3,718	3.755219	.7160107	1.735136	5.798827
Temperature	3,718	28.82315	1.594832	26.22738	33.06827
Mammals & birds	3,718	8.843544	.7041861	6.592516	11.02025

B Wealth index

Table B1: Variables used for the wealth index construction

Variable classification	Variable definition
Housing	Housing tenure status Wall material Floor material Roof material Soil type Material fo the roof Number of rooms
Physical capital	Type of water supply Light source Latrine inside Having mobile phone Having TV Having a post radio Having refrigerator Having freezer Having ventilator Having air conditioner Having computer Having satellite dish Having car Having truck Having iron Having tablet computer Having sewing machine Having dining room Having living room Having chair Having table Having bed Having mattress
Assets	Pocess dwelling Owner of cropland

C Heterogeneity results

Table C1: Heterogeneity by sub-prefecture development level

	biomass/no biomass nightlight>median	collected/purchased nightlight>median	collected/no biomass nightlight>median	biomass/no biomass nightlight<median	collected/purchased nightlight<median	collected/no biomass nightlight<median
PA presence	0.0127	0.00966	-0.0255	0.0309***	0.0286	0.0228**
	(0.57)	(0.39)	(-1.30)	(2.85)	(1.46)	(2.10)
Head age	0.00258***	0.00236***	0.00202***	0.000476*	0.00156***	0.000664**
	(5.35)	(4.54)	(4.80)	(1.67)	(3.90)	(2.25)
Head gender (male)	-0.000605	0.0599***	-0.0119	0.000768	0.0597***	0.00391
	(-0.04)	(3.49)	(-0.92)	(0.10)	(4.61)	(0.47)
No education (head)	ref.	ref.	ref.	ref.	ref.	ref.
Primary education (head)	-0.0113	0.0181	0.00802	-0.00411	0.0104	-0.00279
	(-0.64)	(0.84)	(0.46)	(-0.40)	(0.65)	(-0.29)
Secondary education (head)	-0.0445***	-0.0343*	-0.00748	0.00254	-0.0483***	-0.000357
	(-2.83)	(-1.69)	(-0.48)	(0.28)	(-2.88)	(-0.04)
Higher education (head)	-0.160***	-0.0854	-0.160***	-0.0399*	0.00361	-0.0546*
	(-5.33)	(-1.23)	(-3.96)	(-1.86)	(0.09)	(-1.83)
Agriculture (head)	ref.	ref.	ref.	ref.	ref.	ref.
White collar (head)	-0.127***	-0.464***	-0.246***	-0.0576***	-0.154***	-0.0628***
	(-4.55)	(-10.50)	(-7.15)	(-3.49)	(-4.59)	(-3.11)
Other occupation (head)	-0.113***	-0.386***	-0.178***	-0.0365***	-0.193***	-0.0580***
	(-4.90)	(-16.63)	(-8.19)	(-4.50)	(-14.99)	(-6.67)
Wealth index	-0.904***	-1.486***	-0.928***	-0.303***	-1.300***	-0.465***
	(-21.25)	(-19.21)	(-18.02)	(-10.40)	(-22.93)	(-14.48)
Household size	0.0178***	-0.00335	0.00903***	0.00994***	0.0121***	0.0108***
	(6.19)	(-0.99)	(3.35)	(4.85)	(4.90)	(4.90)
Rainfall	-0.202***	-0.275***	-0.180***	0.0331**	-0.00355	0.0313*
	(-8.36)	(-9.67)	(-7.84)	(1.98)	(-0.13)	(1.84)
Temperature	0.0390***	-0.0159***	0.00831**	0.0134***	-0.000372	0.0134***
	(7.21)	(-2.80)	(2.12)	(5.21)	(-0.10)	(5.43)
Mammals & birds	0.247***	0.194***	0.208***	-0.0642***	-0.0498*	-0.0644***
	(18.84)	(9.22)	(15.04)	(-3.57)	(-1.75)	(-3.46)
Observations	3483	2254	2255	3726	3497	2952
LR test P value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Table C2: Heterogeneity by residence

	collected/purchased urban	purchased/no biomass urban	collected/purchased rural	purchased/no biomass rural
PA presence	-0.0100	0.0801***	-0.0144	-0.0354
	(-0.42)	(2.90)	(-0.97)	(-0.41)
Head age	0.00192***	0.00237***	0.000479	0.000760
	(3.66)	(4.04)	(1.63)	(0.42)
Head gender (male)	0.0770***	0.00512	0.000872	-0.0734
	(4.55)	(0.31)	(0.08)	(-1.13)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	0.00902	-0.0280	-0.00418	-0.0261
	(0.42)	(-1.29)	(-0.33)	(-0.40)
Secondary education (head)	-0.0505**	-0.0387**	-0.00929	0.0557
	(-2.56)	(-2.10)	(-0.70)	(0.84)
Higher education (head)	-0.0803	-0.176***	-0.0150	-0.0165
	(-1.34)	(-5.48)	(-0.43)	(-0.12)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.400***	-0.00456	-0.0855***	-0.00866
	(-9.61)	(-0.09)	(-2.94)	(-0.09)
Other occupation (head)	-0.364***	0.000313	-0.0759***	0.0978*
	(-13.27)	(0.01)	(-7.81)	(1.65)
Wealth index	-1.390***	-1.001***	-0.474***	-0.193
	(-16.85)	(-19.47)	(-9.09)	(-0.80)
Household size	0.00729**	0.0249***	0.00698***	0.0141
	(2.26)	(7.26)	(3.21)	(1.16)
Rainfall	-0.154***	-0.257***	-0.0172	0.371***
	(-5.86)	(-9.27)	(-0.99)	(2.83)
Temperature	0.0113**	0.0628***	0.00856**	0.0590***
	(2.20)	(9.68)	(2.53)	(2.62)
Mammals & birds	0.106***	0.298***	0.0201	-0.324***
	(5.27)	(18.53)	(1.12)	(-2.66)
Observations	2621	3087	3130	373
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Table C3: Surface equals first quartile

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA Surface (first quartile)	0.00510	0.0395**	0.0293**	-0.0353
	(0.34)	(2.23)	(2.18)	(-1.13)
Head age	0.00142***	0.00169***	0.00117***	0.00207***
	(5.08)	(5.25)	(4.59)	(3.58)
Head gender (male)	0.00364	0.0688***	0.00642	-0.00724
	(0.45)	(6.42)	(0.80)	(-0.45)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0136	0.00453	-0.000574	-0.0245
	(-1.33)	(0.34)	(-0.06)	(-1.18)
Secondary education (head)	-0.0216**	-0.0482***	-0.0105	-0.0263
	(-2.36)	(-3.59)	(-1.13)	(-1.45)
Higher education (head)	-0.106***	-0.0215	-0.113***	-0.175***
	(-5.46)	(-0.59)	(-4.41)	(-5.68)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.102***	-0.307***	-0.155***	0.0914**
	(-6.84)	(-9.94)	(-7.92)	(2.42)
Other occupation (head)	-0.0938***	-0.291***	-0.134***	0.106***
	(-8.79)	(-24.62)	(-12.48)	(3.09)
Wealth index	-0.679***	-1.555***	-0.821***	-0.913***
	(-26.83)	(-34.83)	(-29.29)	(-17.88)
Household size	0.0140***	0.00670***	0.0107***	0.0244***
	(8.01)	(3.54)	(6.56)	(7.24)
Rainfall	-0.141***	-0.123***	-0.133***	-0.211***
	(-12.04)	(-7.59)	(-11.60)	(-9.14)
Temperature	0.0311***	0.0000662	0.0220***	0.0664***
	(11.44)	(0.02)	(9.09)	(11.05)
Mammals & birds	0.169***	0.101***	0.155***	0.267***
	(22.80)	(7.17)	(19.47)	(19.36)
Observations	7209	5751	5207	3460
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Table C4: PA surface equals second quartile

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA Surface (second quartile)	0.0218**	0.0117	0.0246**	0.0337
	(1.96)	(0.89)	(2.20)	(1.46)
Head age	0.00141***	0.00169***	0.00119***	0.00203***
	(5.07)	(5.26)	(4.61)	(3.51)
Head gender (male)	0.00369	0.0694***	0.00635	-0.00702
	(0.45)	(6.47)	(0.80)	(-0.44)
No education (head)	ref.	ref.	ref.	ref.
[1em] Primary education (head)	-0.0137	0.00509	-0.000945	-0.0258
	(-1.34)	(0.38)	(-0.10)	(-1.24)
Secondary education (head)	-0.0217**	-0.0484***	-0.0114	-0.0272
	(-2.37)	(-3.60)	(-1.22)	(-1.50)
Higher education (head)	-0.106***	-0.0216	-0.115***	-0.176***
	(-5.46)	(-0.59)	(-4.50)	(-5.73)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.102***	-0.308***	-0.154***	0.0883**
	(-6.87)	(-9.95)	(-7.85)	(2.35)
Other occupation (head)	-0.0939***	-0.292***	-0.132***	0.103***
	(-8.80)	(-24.68)	(-12.27)	(3.00)
Wealth index	-0.681***	-1.559***	-0.821***	-0.916***
	(-26.90)	(-35.07)	(-29.33)	(-17.93)
Household size	0.0140***	0.00647***	0.0109***	0.0245***
	(7.99)	(3.42)	(6.63)	(7.27)
Rainfall	-0.134***	-0.130***	-0.135***	-0.189***
	(-11.87)	(-8.08)	(-12.21)	(-7.96)
Temperature	0.0307***	0.000293	0.0211***	0.0650***
	(11.24)	(0.09)	(8.64)	(10.79)
Mammals & birds	0.165***	0.105***	0.156***	0.255***
	(21.98)	(7.37)	(19.60)	(17.10)
Observations	7209	5751	5207	3460
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Table C5: PA surface equals third quartile

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA Surface (third quartile)	-0.0312***	-0.0685***	-0.0465***	-0.0130
	(-4.05)	(-6.81)	(-6.50)	(-0.76)
Head age	0.00141***	0.00171***	0.00120***	0.00205***
	(5.05)	(5.34)	(4.73)	(3.53)
Head gender (male)	0.00375	0.0688***	0.00512	-0.00671
	(0.46)	(6.44)	(0.64)	(-0.42)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0147	0.00189	-0.00104	-0.0258
	(-1.44)	(0.14)	(-0.11)	(-1.24)
Secondary education (head)	-0.0223**	-0.0474***	-0.00836	-0.0275
	(-2.44)	(-3.56)	(-0.92)	(-1.51)
Higher education (head)	-0.106***	-0.0217	-0.106***	-0.176***
	(-5.52)	(-0.60)	(-4.24)	(-5.74)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.100***	-0.303***	-0.151***	0.0911**
	(-6.77)	(-9.95)	(-7.80)	(2.41)
Other occupation (head)	-0.0922***	-0.289***	-0.131***	0.105***
	(-8.57)	(-24.39)	(-12.11)	(3.06)
Wealth index	-0.670***	-1.518***	-0.798***	-0.911***
	(-26.38)	(-34.02)	(-28.50)	(-17.89)
Household size	0.0140***	0.00647***	0.0107***	0.0246***
	(8.05)	(3.45)	(6.60)	(7.27)
Rainfall	-0.131***	-0.127***	-0.129***	-0.198***
	(-11.94)	(-7.96)	(-12.16)	(-8.84)
Temperature	0.0313***	-0.000346	0.0225***	0.0656***
	(11.37)	(-0.11)	(9.31)	(10.95)
Mammals & birds	0.154***	0.0886***	0.139***	0.257***
	(19.34)	(6.17)	(16.91)	(16.08)
Observations	7209	5751	5207	3460
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Table C6: PA surface equals fourth quartile

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA Surface (fourth quartile)	0.0284***	0.0602***	0.0312***	0.0109
	(2.60)	(4.99)	(3.10)	(0.48)
Head age	0.00143***	0.00174***	0.00119***	0.00206***
	(5.13)	(5.45)	(4.66)	(3.56)
Head gender (male)	0.00370	0.0687***	0.00577	-0.00682
	(0.45)	(6.41)	(0.72)	(-0.42)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0140	0.00454	-0.000452	-0.0253
	(-1.37)	(0.34)	(-0.05)	(-1.22)
Secondary education (head)	-0.0221**	-0.0465***	-0.0106	-0.0271
	(-2.41)	(-3.49)	(-1.14)	(-1.49)
Higher education (head)	-0.106***	-0.0227	-0.112***	-0.175***
	(-5.49)	(-0.63)	(-4.48)	(-5.72)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.100***	-0.305***	-0.153***	0.0920**
	(-6.78)	(-9.99)	(-7.90)	(2.43)
Other occupation (head)	-0.0920***	-0.287***	-0.131***	0.106***
	(-8.60)	(-24.14)	(-12.18)	(3.09)
Wealth index	-0.671***	-1.522***	-0.804***	-0.910***
	(-26.32)	(-34.11)	(-28.28)	(-17.87)
Household size	0.0140***	0.00677***	0.0107***	0.0245***
	(8.06)	(3.59)	(6.63)	(7.26)
Rainfall	-0.150***	-0.151***	-0.150***	-0.206***
	(-13.44)	(-9.19)	(-13.64)	(-8.98)
Temperature	0.0326***	0.00326	0.0241***	0.0660***
	(11.93)	(1.01)	(9.83)	(11.10)
Mammals & birds	0.166***	0.0990***	0.156***	0.262***
	(22.90)	(7.02)	(19.83)	(19.19)
Observations	7209	5751	5207	3460
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Table C7: Effect when PA is a classified forest

	Biomass/ no biomass	Biomas collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA_forest	0.0112	-0.00159	-0.00699	0.0419
	(1.02)	(-0.10)	(-0.59)	(1.59)
Head age	0.00120***	0.00183***	0.00139***	0.00160**
	(4.02)	(5.13)	(4.42)	(2.20)
Head gender (male)	-0.00372	0.0667***	-0.00220	-0.0213
	(-0.44)	(5.82)	(-0.23)	(-1.08)
No education	ref.	ref.	ref.	ref.
Primary education (head)	-0.00719	0.00202	-0.00268	-0.00921
	(-0.68)	(0.14)	(-0.24)	(-0.36)
Secondary education (head)	-0.0105	-0.0476***	-0.00559	-0.00247
	(-1.09)	(-3.23)	(-0.52)	(-0.11)
Higher education (head)	-0.0929***	-0.0406	-0.115***	-0.183***
	(-4.07)	(-0.95)	(-3.59)	(-4.41)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.0728***	-0.261***	-0.113***	0.0832*
	(-4.90)	(-7.72)	(-5.56)	(1.92)
Other occupation (head)	-0.0645***	-0.266***	-0.110***	0.119***
	(-7.11)	(-21.56)	(-10.98)	(3.19)
Wealth index	-0.550***	-1.540***	-0.829***	-0.755***
	(-19.75)	(-32.87)	(-25.92)	(-11.24)
Household size	0.0163***	0.00644***	0.0123***	0.0341***
	(8.00)	(3.21)	(5.59)	(7.60)
Rainfall	0.0177	0.0409	0.0470**	0.0273
	(1.00)	(1.61)	(2.47)	(0.62)
Temperature	0.0279***	-0.00731**	0.0210***	0.0681***
	(10.10)	(-2.12)	(7.63)	(10.53)
Mammals & birds	-0.00473	-0.0935***	-0.0395**	0.0110
	(-0.29)	(-3.55)	(-2.23)	(0.28)
Observations	5638	4957	4031	2288
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Table C8: Effect when PA is a parc

	Biomass/ no biomass	Biomas collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA_parc	-0.00130	-0.0982***	-0.0501***	0.0771
	(-0.04)	(-4.11)	(-3.00)	(1.39)
Head age	0.00203***	0.000600	0.000846**	0.00274***
	(3.69)	(0.94)	(2.23)	(3.30)
Head gender (male)	0.0179	0.0613***	0.0183	0.0124
	(1.08)	(2.90)	(1.53)	(0.51)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0313	0.000787	-0.00641	-0.0468
	(-1.49)	(0.03)	(-0.41)	(-1.47)
Secondary education (head)	-0.0412**	-0.104***	-0.00590	-0.0470*
	(-2.29)	(-3.68)	(-0.43)	(-1.75)
Higher education (head)	-0.103***	0.00368	-0.0588*	-0.135***
	(-3.16)	(0.06)	(-1.68)	(-3.31)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.225***	-0.272***	-0.199***	-0.103
	(-5.62)	(-5.21)	(-4.99)	(-1.07)
Other occupation (head)	-0.219***	-0.279***	-0.186***	-0.0993
	(-6.18)	(-10.71)	(-5.79)	(-1.05)
Wealth index	-0.896***	-1.451***	-0.685***	-1.056***
	(-19.24)	(-15.33)	(-15.07)	(-14.60)
Household size	0.0141***	0.00493	0.00847***	0.0189***
	(4.35)	(1.18)	(4.00)	(4.01)
Rainfall	-0.201***	-0.108***	-0.105***	-0.312***
	(-5.48)	(-3.73)	(-5.21)	(-5.10)
Temperature	0.0460***	-0.0171***	0.0137***	0.0925***
	(4.75)	(-2.83)	(2.83)	(4.26)
Mammals & birds	0.216***	0.127***	0.119***	0.311***
	(8.63)	(5.83)	(8.32)	(7.16)
Observations	2363	1443	1751	1532
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Table C9: Effect when PA is a nature reserve

	Biomass/ no biomass	Biomas collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA_ReserveNatur	0.208***	0.0137	0.187**	0.416***
	(3.10)	(0.33)	(2.32)	(3.74)
Head age	0.00182***	0.000931	0.00190***	0.00235
	(2.64)	(0.97)	(2.59)	(1.52)
Head gender (male)	0.00462	0.0469	0.0158	-0.00646
	(0.22)	(1.60)	(0.73)	(-0.15)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.00871	-0.00190	-0.0149	0.000401
	(-0.33)	(-0.06)	(-0.58)	(0.01)
Secondary education (head)	-0.00663	-0.106***	0.000989	0.0197
	(-0.28)	(-2.63)	(0.04)	(0.40)
Higher education (head)	-0.0434	-0.120	-0.0943	-0.0617
	(-0.99)	(-1.09)	(-1.22)	(-0.75)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.135***	-0.209***	-0.159***	-0.140
	(-4.22)	(-2.76)	(-3.66)	(-1.02)
Other occupation (head)	-0.151***	-0.283***	-0.184***	-0.155
	(-6.46)	(-9.60)	(-6.36)	(-1.14)
Wealth index	-0.705***	-1.382***	-0.874***	-1.070***
	(-10.35)	(-8.92)	(-10.51)	(-7.39)
Household size	0.0203***	0.00752	0.0119***	0.0399***
	(4.13)	(1.33)	(2.60)	(4.28)
Rainfall	-0.0554	0.136**	0.0309	-0.206**
	(-1.19)	(2.29)	(0.72)	(-2.13)
Temperature	0.0346***	-0.0295***	0.0151**	0.0909***
	(4.32)	(-3.49)	(2.12)	(4.50)
Mammals & birds	0.0646*	-0.179***	-0.0233	0.213***
	(1.70)	(-3.00)	(-0.65)	(2.74)
N	1038	866	742	468
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Table C10: Effect by PA type (national or international)

	Biomass/ no biomass	Biomas collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass	Biomass/ no biomass	Biomas collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA_National	0.0268**	0.000794	-0.0000855	0.0676***				
	(2.10)	(0.05)	(-0.01)	(2.60)				
PA_International					0.105	-0.0242	0.0126	0.360*
					(1.42)	(-0.42)	(0.25)	(1.80)
Head age	0.00146***	0.00169***	0.00118***	0.00213***	0.00164**	0.000794	0.00165**	0.00224
	(5.15)	(5.17)	(4.52)	(3.67)	(2.46)	(0.88)	(2.38)	(1.40)
Head gender (male)	0.00404	0.0699***	0.00634	-0.00670	0.000670	0.0564*	0.0112	-0.0144
	(0.49)	(6.44)	(0.78)	(-0.42)	(0.03)	(1.95)	(0.55)	(-0.33)
No education (head)	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
Primary education (head)	-0.0124	0.00436	-0.000753	-0.0219	-0.00599	0.00472	-0.00681	0.000734
	(-1.20)	(0.33)	(-0.08)	(-1.05)	(-0.24)	(0.15)	(-0.29)	(0.01)
Secondary education (head)	-0.0228**	-0.0475***	-0.0116	-0.0277	-0.00425	-0.139***	0.00101	0.0277
	(-2.45)	(-3.49)	(-1.23)	(-1.53)	(-0.18)	(-3.33)	(0.04)	(0.52)
Higher education (head)	-0.107***	-0.0246	-0.116***	-0.175***	-0.0402	-0.0485	-0.0800	-0.0684
	(-5.44)	(-0.65)	(-4.50)	(-5.68)	(-0.92)	(-0.56)	(-1.13)	(-0.78)
Agriculture (head)	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
White collar (head)	-0.103***	-0.313***	-0.159***	0.0919**	-0.130***	-0.180***	-0.140***	-0.154
	(-6.85)	(-10.02)	(-7.96)	(2.42)	(-4.19)	(-2.70)	(-3.65)	(-1.14)
Other occupation (head)	-0.0954***	-0.295***	-0.136***	0.105***	-0.148***	-0.253***	-0.173***	-0.168
	(-8.80)	(-24.54)	(-12.43)	(3.05)	(-6.73)	(-9.04)	(-6.76)	(-1.26)
Wealth index	-0.677***	-1.568***	-0.828***	-0.886***	-0.695***	-1.486***	-0.869***	-1.081***
	(-26.43)	(-34.96)	(-28.83)	(-17.38)	(-10.38)	(-11.03)	(-11.58)	(-7.28)
Household size	0.0138***	0.00676***	0.0108***	0.0238***	0.0208***	0.00255	0.0119***	0.0433***
	(7.84)	(3.53)	(6.50)	(7.10)	(4.25)	(0.48)	(2.73)	(4.42)
Rainfall	-0.160***	-0.137***	-0.146***	-0.239***	-0.0474	0.0350	0.0244	-0.182*
	(-12.25)	(-7.78)	(-11.38)	(-9.03)	(-1.05)	(0.64)	(0.60)	(-1.77)
Temperature	0.0340***	0.000606	0.0234***	0.0708***	0.0302***	-0.0240***	0.0132**	0.0829***
	(12.04)	(0.18)	(9.48)	(11.58)	(3.73)	(-3.36)	(2.00)	(3.87)
Mammals & birds	0.183***	0.103***	0.163***	0.289***	0.0510	-0.0343	-0.0205	0.177**
	(22.47)	(6.90)	(18.95)	(18.41)	(1.37)	(-0.71)	(-0.60)	(2.09)
Observations	7076	5621	5092	3439	1070	898	791	451
LR test P value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Table C11: Effect depending on the level of protection of the PA

	Biomass/ no biomass	Biomas collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
Integral PA	-0.0476***	-0.0715***	-0.0557***	-0.0668**
	(-4.51)	(-4.89)	(-5.85)	(-2.47)
Head age	0.00140***	0.00181***	0.00106***	0.00210***
	(4.62)	(5.41)	(3.89)	(3.37)
Head gender (male)	0.00513	0.0700***	0.00360	-0.00306
	(0.59)	(6.17)	(0.43)	(-0.18)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0162	0.00388	-0.00148	-0.0286
	(-1.48)	(0.27)	(-0.14)	(-1.29)
Secondary education (head)	-0.0229**	-0.0372***	-0.0115	-0.0311
	(-2.36)	(-2.65)	(-1.17)	(-1.62)
Higher education (head)	-0.114***	-0.0191	-0.117***	-0.187***
	(-5.25)	(-0.48)	(-4.13)	(-5.63)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.0869***	-0.313***	-0.135***	0.122***
	(-5.41)	(-9.24)	(-6.51)	(3.17)
Other occupation (head)	-0.0744***	-0.291***	-0.113***	0.144***
	(-6.42)	(-22.79)	(-10.52)	(4.14)
Wealth index	-0.639***	-1.550***	-0.758***	-0.864***
	(-22.96)	(-33.01)	(-24.73)	(-15.58)
Household size	0.0130***	0.00635***	0.0109***	0.0220***
	(7.05)	(3.18)	(6.22)	(6.15)
Rainfall	-0.108***	-0.116***	-0.0967***	-0.169***
	(-6.92)	(-6.15)	(-6.93)	(-4.86)
Temperature	0.0293***	0.00542	0.0210***	0.0602***
	(9.66)	(1.62)	(8.49)	(9.07)
Mammals & birds	0.139***	0.0917***	0.127***	0.226***
	(12.06)	(5.41)	(11.43)	(8.25)
Observations	6228	4962	4496	2998
LR test p value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses

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

Robust standard errors

Chapter 3

Indoor air pollution and health in Côte d'Ivoire : does the age group matter?

1 Introduction

Degradation of air quality is undoubtedly one of the major environmental challenges in developing countries and especially in sub-Saharan Africa. Indeed, the socio-economic development of Africa in general and the West African sub-region in particular, increases the quantities of pollutants discharged into the atmosphere (Coalition pour le Climat et l'Air pur, 2019). According to World Health Organisation (WHO thereafter), air pollution is now the greatest environmental risk to health with more than eight (8) million premature deaths in 2014 worldwide. In 2017, an estimated 670,000 premature deaths in Africa were linked to exposure to air pollution; of which about 13,000 were in Côte d'Ivoire (Coalition pour le Climat et l'Air pur, 2019). Increasing levels of urbanisation and poor urban planning in sub-Saharan Africa have contributed to rising levels of air pollution and, consequently, increased adverse health effects, including non-communicable diseases. Indoor air pollution was the largest contributor to deaths from non-communicable diseases in sub-Saharan Africa in 2016 (Milanzi et al., 2021). And this pollution associated with the use of biomass as fuel was responsible for 7 million deaths in 2016 and most of these deaths occurred in low- and middle-income countries (Kouao et al., 2019). Furthermore, according to The LANCET[1], in Côte d'Ivoire, for the whole population, lower respiratory infections were responsible for 9.31% of total deaths in 2019. And, the top 3 causes of death in children under 5 years of age were neonatal disorders (35.56%), malaria (21.59%) and lower respiratory infections (13.76%) in 2019.

Côte d'Ivoire is aware of the issues related to air pollution caused by economic development and has joined several international conventions and mechanisms, including the United Nations Framework Convention on Climate Change (UNFCCC) and the Climate and Clean Air Coalition (CCAC) (Coalition pour le Climat et l'Air pur, 2019). This awareness has also manifested itself at the sub-regional level with the adoption in 2009 of the Abidjan Agreement, a regional framework agreement for the improvement of air quality in Central and West Africa Coalition pour le Climat et l'Air pur (2019). This agreement is a starting point to address the issue of air pollution in Central and West African countries. In October 2018, in the framework of the Abidjan agreement, a workshop was initiated in Abdijan with the aim of producing an evaluation report and a roadmap 2019-2023 (UNEP, 2019).

From a technical support point of view, Côte d'Ivoire benefits from a program financed by Norway and Sweden and implemented in seven cities, five of which are in Africa (Abidjan, Addis Ababa, Kigali, Nairobi and Ouagadougou) and two in Asia-Pacific (Agra and Phnom Penh) to help *better define and measure the magnitude of air pollution and its*

[1]https://www.thelancet.com/lancet/visualisations/gbd-compare

main sources, review regulatory and institutional frameworks and develop recommendations through a consultative process with key stakeholders. Program is linked to regional and sectoral activities carried out by UNEP and its partners in the areas of clean mobility, waste management and clean industries (UNEP, 2019). The country has embarked on a process of reducing the footprint of its economic development on its natural environment through the commitment to reduce its greenhouse gas emissions by 28% by 2030 and the adoption of an Air Quality Decree to control air pollution (UNEP, 2019).

In addition, as part of the implementation of the ECOWAS Renewable Energy Policy (PERC), Côte d'Ivoire put in place a National Renewable Energy Action Plan (PANER) in 2016[2]. The main objective of the PANER is to contribute to the achievement of the targets set by the PERC for 2030. To achieve this overall goal, Côte d'Ivoire has set itself some specific objectives. The first is to increase access to clean energy and to reduce the demand for polluting energy, more specifically to reduce the amount of wood energy used to meet household energy needs. To achieve this, awareness-raising activities on the use of improved stoves and butane gas have been undertaken (**?**). The second is the reduction of polluting emissions and the preservation of the forest cover. Indeed, in terms of cooking, biomass energy (firewood, charcoal, vegetable waste) represents a little more than 2/3 of the total final energy consumption of households (**?**). In view of the consumption of wood-energy, the vegetation cover of Côte d'Ivoire risks disappearing if nothing is done, as the Ivorian forest has gone from 9 million ha in 1965 to 2.8 million ha in 2021[3]. To achieve this, the PANER aims to increase the share of the population consuming modern alternative cooking fuels such as LPG to 90% by 2030 (**?**). Another important specific objective is to achieve gender equity in terms of cooking fuel use (**?**). Through PANER, Côte d'Ivoire is working to reduce the use of solid fuels (coal and biomass). This could consequently improve indoor air quality through the use of clean fuel.

Worldwide, 41% of households, or over 2.8 billion people, use solid fuels for cooking and heating (Amegah and Jaakkola, 2016). In Asia and sub-Saharan Africa where these fuels are mainly used, women, who are usually responsible for cooking, and their young children are most exposed to the resulting air pollution (Amegah and Jaakkola, 2016). Solid fuels are still widely used and intervention efforts are apparently not keeping pace with population growth in developing countries(Amegah and Jaakkola, 2016). According to data from the 2015 Household Living Standards Survey, 81.27% of households in Côte d'Ivoire use biomass (charcoal or wood) as fuel for cooking. The objective of this study is to show the causal relationship between indoor air quality and the risk of respiratory diseases in Côte d'Ivoire. To do this, I create an original indoor air pollution index to

[2]https://www.householdenergypolicies.org/policy/173
[3]https://www.timbertradeportal.com/en/republic-of-cote-divoire/176/country-context

approximate level of pollution to which households were exposed in Côte d'Ivoire in 2015 when they are inside the house.

This study differs from the previous ones on several points. The first concerns the sample. Previous studies have focused on a particular area of Côte d'Ivoire, and more precisely on one municipality in the city of Abidjan (René et al., 2019; Rosine et al., 2021). While this study focuses on all the sub-prefectures of Côte d'Ivoire. The broadening of the study sample allows me to have a wider overview of the effects of indoor air pollution on household members health. The second and major contribution of the study is the creation of an original indoor air pollution index based on emission sources. This allows us to approximate indoor air quality. Another contribution is that the analysis is done by age group. This is of interest with regard to the development of appropriate public policies. A mixed-effect logistic model has been used to perform the analysis. Random effects at the household and sub-prefecture level were added to the model to take into account certain factors that may affect the health of household members. The results show that indoor air pollution increases the risk of respiratory diseases among children under five. The effects vary according to the characteristics of the households and the household's place of residence.

The rest of the study is organised as follows: the next section presents the literature review on the subject. The materials are presented in the third section. The fourth and fifth sections describes respectively the stylized facts and the econometric analysis. Then, the sixth and seventh sections are devoted respectively to the presentation of the robustness checks and the heterogeneity tests. The last section discusses the conclusion and policy implications.

2 Background

Larson and Rosen (2002) support the idea that there is a willingness to pay to prevent indoor air pollution in developing countries. This demand for better air quality is partly related to the health effects of pollution. In this section I will first discuss the different sources of indoor air pollution and in the second part I will talk about the health effects on household members.

2.1 Sources of indoor air pollution and major toxic pollutants

Agbo et al. (2021) show that vehicle traffic, industries, forest fires and biomass burning are important sources of PM, CO, NO2, SO2 and VOCs in Africa. Also the Sahara desert is an important source of PM especially during the harmattan. Average indoor concentrations of PM, CO, NO2 and SO2 exceed WHO limit values and even more so in poorly ventilated wood-fired kitchens in rural areas. In this sense, Abdul Raheem et al. (2022) show that NO2, SO2, and CO concentrations were higher in kitchens using charcoal and firewood in Nigeria. In addition, firewood contributed significantly more than charcoal to the emission of the pollutants. This implies a potentially high exposure of women and children in Africa.

Biomass is a source of energy that has been used for many years and by about half the world's population. The majority of use is in developing countries for economic activities, basic cooking, heating and lighting (Balat and Ayar, 2005). According to Bruce et al. (2006), in rural areas of several african countries, biomass is the main fuel used by almost 100% of the population. Energy can be obtained by direct or indirect combustion. The use of this type of energy is the main source of indoor air pollution in these countries because biomass combustion generates important pollutants such as airborne particles and polycyclic organic matter, which include a number of carcinogenic substances (Ludwig et al., 2003).

Furthermore characteristics of the house are also an important source of pollution. First of all, level of ventilation is very important because it favours the evacuation of pollutants from the indoor air. The more the house is well ventilated, the better the indoor air quality (Xu et al., 2010; Apte and Salvi, 2016; Kouao et al., 2019). Kouao et al. (2019) prove this by looking at the exposure to outdoor and indoor air pollution of children under 5 years old in the municipality of Yopougon in Abidjan. The results reveal the number of windows in bedrooms and kitchens located outside are negatively related to the level of PM2.5 concentration inside the house. Pollutants are also related to materials (e.g. cement), coatings, paint and furnishings. The use of certain construction materials contributes to the emission of volatile organic compounds. For example, the fact that the wall or floor or roof is made of cement releases volatile organic compounds that affect the level of indoor air pollution (Apte and Salvi, 2016). In addition, the use of some high-tech devices increase the level of ozone in home (Apte and Salvi, 2016). Also, the use of insecticides and pesticides (e.g. mosquito repellents), deodorants, perfumes and incense release organic compounds that could be toxic (Apte and Salvi, 2016). Table 3.1 is a summary of the different sources of household air pollution according to Apte and Salvi (2016).

In addition to internal sources, there are also external sources that contribute to the deterioration of indoor air quality. Pollutants produced outside influence the level of indoor air pollution (Jones, 1999; Koponen et al., 2001). This is because pollutants are transported by the wind, which is considered the main carrier of concentrated pollutants in the air. These wind-borne pollutants are concentrated in houses.

Table 3.1: Sources of household air pollution (Apte and Salvi, 2016)

Sources of household air pollution	**Examples**
Cooking methods (using liquefied petroleum gas or electricity)	Stir frying, frying, roasting, grilling, baking, basting, and broiling methods which lead to an increase in particulate matter (PM2.5)
Biomass fuels	Wood, crop residue, animal dung, and charcoal
Tobacco smoke	Active smokers and second-hand and third-hand smoke
Incense sticks	Agarbatti and dhoop (incense sticks), Bakhoor, and Oudh
Mosquito repellents	Mosquito coils, flammable paper mats, and aerosols
Cleaning agents, products of personal care, air fresheners, wood varnishes, paint, and carpet solvents	Volatile organic compounds
Fire-retardant foam-containing furniture, electronic gadgets, and builddding material	Polybrominated diphenyl ethers
Fungi such as Aspergillus, Cladosporium, and Penicillium Bacteria such as Legionella	Damp walls and ill-maintained air conditioning
Domestic pets	Pet dander

Also, Table 3.2 from Smith et al. (2004) gives an idea about the main indoor air pollutants and their emission sources. We can see that there are several types of pollutants. Some of them come from the type of fuel used. These include fine particles, carbon monoxide, polycyclic aromatic hydrocarbons, nitrogen oxides and volatile and semi-volatile organic compounds. The use of solid or biomass fuel (wood or charcoal) for cooking, heating or lighting leads to increased concentrations of these pollutants. Other pollutants such as sulphur oxides, arsenic and fluorine are emitted through coal combustion. Building materials can cause indoor air pollution through the emission of pollutants such as aldehydes, asbestos and radon. Again in Table 3.2, it can be seen that most pollutants have several emission sources. In addition, it is important to note that the level of concentration of these pollutants will also depend on the level of ventilation in the house or kitchen. Indeed, when the house has a better ventilation system, this favours the dissipation of pollutants.

At the end of this section, one could conclude that the main source of indoor air pollution in sub-Saharan Africa is the use of traditional fuels. The following lines will discuss the adverse effects of these emitted pollutants on the health of household members.

Table 3.2: Major toxic pollutants of indoor air (Table from (Smith et al., 2004)

Pollutant	Major indoor sources
Fine particles	Fuel/tobacco combustion, cleaning, fumes from food being cooked, e.g. from cooking oil
Carbon monoxide	Fuel/tobacco combustion
Polycyclic aromatic hydrocarbons	Fuel/tobacco combustion, fumes from food being cooked, e.g. from cooking oil
Nitrogen oxides	Fuel combustion
Sulfur oxides	Coal combustion
Arsenic and fluorine	Coal combustion
Volatile and semi-volatile organic compounds	Fuel/tobacco combustion, consumer products, furnishings, construction materials, fumes from food being cooked, e.g. from cooking oil
Aldehydes	Furnishing, construction materials, cooking
Pesticides	Consumer products, dust from outside
Asbestos	Remodelling/demolition of construction materials
Lead[a]	Remodelling/demolition of painted surfaces
Biological pollutants	Moist areas, ventilation systems, furnishings
Free radicals and other short-lived, highly reactive compounds	Indoor chemistry
Radon	Soil under building, construction materials

[a] Lead-containing dust from deteriorating paint is an important indoor pollutant for occupants of many households, but the most critical exposure pathways are not usually through air. See chapter 19.

Source: Zhang and Smith (2003).

2.2 Indoor air pollution and health

Poor indoor air quality has adverse effects on people's health. In this section I will first discuss the different impacts of indoor air pollution on children's health, then on women's health and finally on the health of the elderly.

Previous studies show that indoor air pollution affects the health of children in several ways. In this sense, Basu et al. (2020) show that indoor air pollution induced by solid fuel use increases the risk of neonatal and infant mortality by 4.9% in India. And Kinney et al. (2021) found that prenatal household air pollution exposure increased risk of pneumonia and severe pneumonia in the first year of life of children in Ghana. Air pollution also causes underweight babies (Hackley et al., 2007). Furthermore, Edwards and Langpap (2012) finds that children aged 0-5 years living in households that use more wood, and where exposure to indoor air pollution is higher because the mother cooks while caring for the children or because cooking takes place indoors, are more likely to have symptoms of respiratory infection in Guatemala. In the same vein, Padhi and Padhy (2008) show that exposure to cooking smoke from biomass combustion is significantly associated with decreased lung function and increased prevalence of asthma among children in rural India. Also, solid fuel smoke has most of the toxins found in tobacco smoke and has also been associated with various diseases, such as acute respiratory infections in children when exposed to solid fuel smoke (Pérez-Padilla et al., 2010). Ranathunga et al. (2019) assess the association between household air pollution due to solid fuel combustion and self reported childhood respiratory tract diseases among children under 5 in Sri Lanka. They find significantly higher concentrations of CO and PM2.5 in households using biomass as cooking fuel. The risk of developing asthma was 1.6 times higher in the highly exposed group compared to the less exposed children. Health effects of indoor air pollution on children under 5 years have been tested also in Côte d'Ivoire. In this sense, René et al. (2019) are interested in the relationship between indoor air pollution from biomass burning and the prevalence of asthma in children under 5 years old in the municipality of Yopougon in Abidjan. They find a positive relationship between nocturnal dry cough and outdoor PM2.5 concentration and a relationship between wheezing and indoor PM2.5 concentration. Furthermore, a study by Rosine et al. (2021) on a sample of 200 asthma patients in the commune of Yopougon in Adidjan shows 63% of individuals in the sample combined the use of charcoal and butane gas as fuel at home. This result supports the idea that the use of biomass as fuel increases the level of indoor air pollution. In addition, Yu (2011) find an improvement in the respiratory health of children aged five and under in rural China through stove and behavioural interventions to reduce indoor air pollution.

Indoor air pollution also affects women's health. According to de Koning et al. (1985), in rural areas of developing countries, women are most exposed and so is the foetus for pregnant women and children. The effects of this pollution vary according to the weather conditions, the size and ventilation level of the house and the type of food being cooked (de Koning et al., 1985). Women are the most vulnerable to indoor air pollution and the effect on the level of morbidity is higher for women aged between 14 and 40 years (Dutta and Banerjee, 2014). In the same vein, Oluwole et al. (2013) show that the use of firewood for cooking is responsible for indoor air pollution in Nigeria and a deterioration in the respiratory health of women. The authors find that the use of low-emission stoves reduces the level of pollution and thus reduces the symptoms of respiratory diseases. Air pollution is also the cause of underweight births, intrauterine pregnancies, premature births and abortions (Hackley et al., 2007). Similarly, through a meta-analysis, Gebremeskel Kanno and Hussen Kabthymer (2021) shows that mothers living in households that use biomass as fuel have a 74% higher risk of giving birth to a low birth weight child compared to mothers living in households without air pollution due to biomass fuel use. The study concludes that indoor air pollution from cooking fuels increases the risk of low birth weight in sub-Saharan Africa. Also, solid fuel smoke has been associated with various diseases, such as chronic obstructive pulmonary disease and lung cancer in women (Pérez-Padilla et al., 2010).

The health of the elderly is also affected by indoor air pollution. Indeed, the effects of indoor air pollution are much more severe in the elderly due to their weakened immune system and multiple health risk factors Rani et al. (2021). For example, Weuve et al.

(2012) show that long-term exposure to PM10 and PM2.5 is associated with significant cognitive decline in elderly women in the US and also increases the risk of breast cancer. In addition, Rani et al. (2021) investigated the effect of indoor air pollution from fuel use on cognitive function in elderly people in India. The findings show lower cognitive function scores in elderly people living in households using solid fuels. And elderly people from low socio-economic backgrounds were more exposed to indoor air pollution than their counterparts, which indirectly increases the risk of poor cognitive function. Qiu et al. (2019) looking at middle-aged and elderly people in China, using the propensity score matching method, they find that indoor air pollution increases the likelihood of being diagnosed with respiratory and cardiovascular diseases including lung disease, heart disease, and hypertension, and reporting poor health status. They also find a significant adverse impact on cognitive abilities, specifically short-term memory and mathematical reasoning. In the same vein Saenz et al. (2018) find that indoor air pollution may be an important factor in the cognitive health of older people in Mexico.

Exposure of individuals to indoor air pollution from biomass burning is the cause of several diseases in developing countries. Indeed, exposure to emissions from these types of fuel have been found to be associated with many respiratory diseases such as acute lower respiratory tract infections, chronic obstructive pulmonary disease, lung cancer, pulmonary tuberculosis, asthma, childhood pneumonia, pneumoconiosis, bronchitis, head and neck cancers and cardiovascular diseases (Prasad et al., 2012; Balmes, 2019; Simkovich et al., 2019). This is the case of Albalak et al. (1999) who study the relationship between biomass burning and chronic bronchitis in Bolivia. They find a positive relationship between the prevalence of chronic bronchitis and cooking indoors using biomass as an energy source. This is because the pollutants emitted settle in the respiratory tract and cause illness. Also, the pollution resulting from biomass burning contains carcinogenic polycyclic aromatic hydrocarbons (PAHs) which cause blood diseases and several human morbidities in developing countries as these countries account for 99% of the world's biomass fuel use (Kamal et al., 2015; Prasad et al., 2012). According to Balmes (2019), the mechanisms by which solid fuel smoke causes health problems in humans are quite similar to those involved in tobacco smoke. Indeed, after smoke inhalation, oxidative stress in the airways and alveoli leads to stimulation of alveolar macrophages and damage to the mucosal lining of the epithelium, which in turn attracts inflammatory cells from the circulation. This local pulmonary inflammatory reaction can spread to the systemic circulation and contribute to problems in other organs, such as the cardiovascular system, and the foetus in pregnant women. Alveolar macrophages loaded with carbon particles from smoke may contribute to an increased risk of respiratory tract infections. Furthermore, the pathways involved in lung carcinogenesis induced by solid fuel smoke are probably identical to those by which tobacco smoke induces lung cancer. Semple et al. (2014); Mocumbi et al. (2019);

Pope III et al. (2009) show that indoor air pollution increases the risk of cardiovascular disease and that premature cardiovascular death and disability in sub-Saharan African countries could be prevented by addressing the use of biomass fuels by the poorest households.

3 Materials

The strength of this study lies in the construction of an original database that combines ambiant air quality and nightlight data from satellite imagery with data from the 2015 Household Living Standards Survey in Côte d'Ivoire. Also, the hierarchical structure of this database allows contextual effects to be taken into account. Using this database, I construct an original indoor air pollution index. This section describes the data used and the data sources.

3.1 Data

The unit of observation is the individual, whose main characteristics are given by the 2015 household living standards survey. Main purpose of the Côte d'Ivoire household living standards survey is to provide the information needed to improve planning and evaluation of economic and social policies in Côte d'Ivoire. The survey provides information on household composition, education, employment and health, among other things. It was conducted by the National Institute of Statistics (INS) of Côte d'Ivoire. The sampling frame used to draw the sample is the 2014 General Census of Population and Housing. The sampling is based on a two-stage draw. The first stage consists of a proportional allocation of the Enumeration Areas (EAs). The second is a systematic drawing of 12 households per enumeration area. The total sample obtained consists of 12,900 African households residing in Côte d'Ivoire (INS, 2023). Furthermore, I do not use the DHS databases because the information on household residence is limited to the regional level only. In order to have more variability, I choose the household living standards survey data to do the analysis.

The study is based on a sample of 2060 individuals divided into four (4) age groups who had visited a health care provider in the last 4 weeks at the time of the survey in 2015. I use the dependency ratio to create age groups to see how the impact of indoor air pollution varies according to age group. Dependency ratio is calculated according to the age structure of the population. It corresponds to the ratio of the number of individuals who are supposed to be "dependent" on others for their daily life (young and old people) and the number of individuals who are able to assume this dependence of individuals able to assume this burden. Generally, the number of individuals under 15 and over 65 years of age is related to the population aged 15 to 64 years because it is assumed that individuals aged 15 to 64 years are workers and the others are dependents (Delaunay and Guengant, 2019). Based on this indicator, I obtain 4 age groups. The first group is made up of children under the age of 5. I focus on this age group because they are very vulnerable due to the immaturity of their organs. The second group is children between 5 and 14 years old. The third group includes people between 15 and 64 years old who are considered active people. And the fourth group is for people aged 65 and over.

In addition to the survey data I use the database of van Donkelaar et al. (2018) which contains annual concentrations of fine particles at ground level (PM2.5), without dust and sea salt. The data are gridded to 0.01 degrees and expressed in micrograms per cubic metre. These data give an idea of the ambient air pollution level and are also used in the construction of the indoor air pollution index. I also use night-time luminosity data which is satellite imagery data from The Earth Observations Group database. These data allow me to have information on the level of development of the sub-prefectures of Cote d'Ivoire. The concentrations of PM2.5 and luminosity data at sub-prefecture level are extracted using QGIS software.

The following lines describe the variables used in the analysis and obtained from the constructed database.

3.2 Outcome variable

The dependent variable informs us about the number of people who report having recently consulted a doctor because of a respiratory or cardiac disease during the last 4 weeks (question C.1.c in the survey form). The value is 1 when the individual consults for reasons related to nasal breathing (sinus), pulmonary breathing (chest, lungs), asthma, flu, sore throat or heart problems. And the variable is 0 when the individual consulted because of another health problem. In the rest of the analysis, I will refer to the risk of respiratory diseases and not to the risk of respiratory and cardiac diseases because most of the diseases mentioned above are related to the respiratory tract. In the sample, 2862 individuals consulted a doctor for various health reasons (Table A1).

3.3 Interest variable

Indoor air pollution measures

Several measures are used to measure indoor air quality. Some researchers use indirect measurements and others use direct measurements. The indirect measure frequently used is the type of fuel used for cooking, heating or lighting. Indeed, inefficient combustion of solid fuels in poorly ventilated homes is a major source of exposure to indoor air pollution (Balmes, 2019). As a result, some previous studies use the type of fuel used to approximate the level of indoor air pollution and its different impacts on the health status of household members (Pérez-Padilla et al., 2010; Saenz et al., 2018; Balmes, 2019; Qiu et al., 2019).

In addition, direct measurements of indoor air pollution are used to investigate its impact on health (Ranathunga et al., 2019; Rani et al., 2021; Kinney et al., 2021). These authors use sensors (Kinney et al., 2021) which can be placed in the kitchen, living room or bedroom. The pollutants measured are usually particulate matter (PM10, PM2.5 or PM0.1), carbon monoxide, nitrogen dioxide and sulphur dioxide and are harmful to health (Chen and Zhao, 2011; Leung, 2015; Saenz et al., 2018).

These previous measures have limitations. The indirect measure is an incomplete measure because it only captures a part of the indoor pollution. Indeed, indoor air quality may depend on outdoor air quality because ambient air pollutants are transported inside houses. It is therefore very important to take into account the outdoor air quality. Furthermore, direct measurement of indoor air quality is more difficult to implement, which limits its deployment. Indeed, this kind of measurement on a national scale require a lot of financial resources. This is why it is usually done for a few households and in one or more localities. In this study I compute an original measure of indoor air pollution. To my knowledge, this study is the first to construct this type of indoor air quality index. This indexr has some advantages over previous measurements because it combines internal and external sources of pollution and gives an idea of the indoor air quality of households in all sub-prefectures of Côte d'Ivoire in 2015. The following section gives the details of the construction of the indoor air pollution index.

Indoor air pollution index

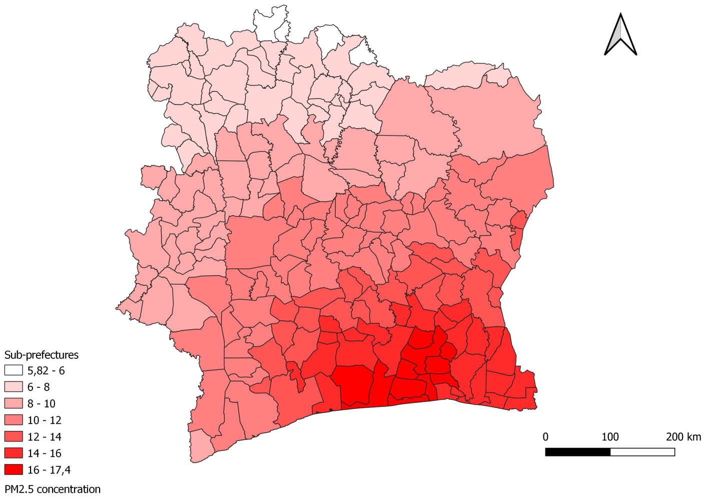
Indoor air pollution results from emissions of pollutants from both external and internal sources. This section describes the construction of the index. For this purpose I combine external and internal sources of pollution. In the first part of the section I discuss external sources and the second part focuses on internal sources.

Primary source of ambiant air pollution in Côte d'Ivoire is road traffic. Indeed, cars that serve as public transport and are commonly called woro-woro and gbaka are old. Despite the decree banning import of vehicles more than five years old, the fleet of vehicles remains old and polluting. The older the vehicles, the higher their particle emission rate. In addition, most of the cars used run on diesel. Another source of pollution is the burning of waste and agricultural residues in urban and rural centres (Ehsani et al., 2017). This ambient air pollution affects indoor air quality because pollutants from outside, carried by the wind, are deposited inside houses. This is why I take into account the ambient air quality in the construction of the index. To do that, I use the annual average concentration of PM2.5 set by WHO that the country should not exceed in order to ensure that the air people breathe is safe. The new annual limit set by the WHO is 5 $\mu g/m^3$. Thus, the "outdoor pollution" indicator equals 1 when the sub-prefecture has an annual concentration of fine particles above 6 $\mu g/m^3$ [4] and 0 otherwise. Graph 3.1 shows the average concentration level of fine particles. In the graph, the sub-prefectures located in the south and south-east have a very high level of PM2.5 concentration compared to the other sub-prefectures. This level of PM2.5 would be explained by the fact that the autonomous district of Abidjan is located in this area. Indeed, Abidjan has a high level of PM2.5 mainly because of the very dense road traffic. In addition, industries, domestic fires, bush fires and open dumps are also at the origin of poor ambient air quality in Cote d'Ivoire in 2015 (UNEP). Thermal power plants are also a source of ambient air pollution. Indeed, in 2015, 50.6% of the electricity came from fossil fuel and 49.4% from renewable energy (UNEP). Most of these natural gas-fired power plants are located in Abidjan. They thus contribute to the deterioration of the ambient air quality of the locality.

Furthermore, indoor air quality depends on household behaviour, especially with regard to the choice of energy for cooking and lighting. I construct a "fuel" indicator which is equal to 1 when cooking fuel is biomass and 0 if households use clean fuel like gas or electricity. the households for which I have information on the type of fuel, 81.07% use biomass as cooking fuel, mainly firewood (wood collected or purchased) and charcoal and only 18.93% use clean fuel. The second indicator "lighting mode" is 1 when it is a polluting mode and 0 if the lighting mode is electricity, solar panel or torch. Only 2.95% of the sample uses a polluting lighting mode. These include the use of lamps (paraffin, oil, gas), generators and firewood. Since the type of cooking fuel and lighting system are not the only source of indoor air pollution, I also take into account the characteristics of the household accommodation such as the type of housing and the type of construction

[4] I used the value of 6 $\mu g/m^3$ instead of 5 $\mu g/m^3$ because the annual ambient air pollution level of each sub-prefecture exceeds 5 $\mu g/m^3$. Since we want to get as close as possible to the revised value (5 $\mu g/m^3$ instead of 10 $\mu g/m^3$) of the annual pollution level limit, we choose 6 $\mu g/m^3$.

Figure 3.1: PM2.5 concentration in ambient air in $\mu g/m^3$



Source: Author's own elaboration

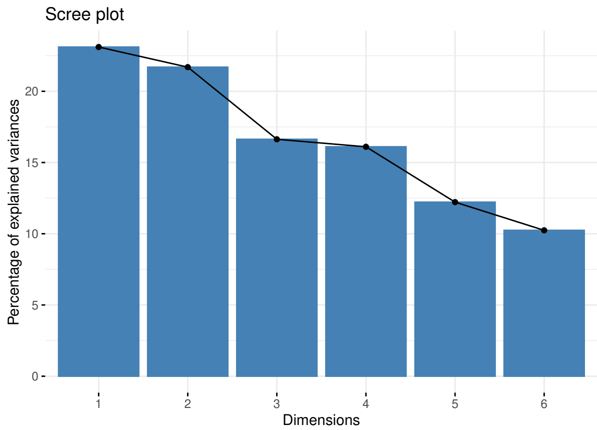
material of the dwelling.

I create an indicator to categorise the type of housing. The indicator "type of dwelling" is 1 when it is a less ventilated dwelling and 0 otherwise.The data shows that 14.97% live in less ventilated houses such as traditional huts or shacks and the rest of the sample live in well-ventilated dwellings such as villas, flats or courtyard houses. The "floor material" indicator is 1 when floor of the dwelling is made of cement (68.2% of the sample) and 0 if floor is made of tile, marble, carpet, wood or soil. otherwise. "Roof material" indicator is 1 when the roof is made of concrete (2.21% of the sample) and 0 if the roof is made of plant fibre, sheet metal or tiles.

Using multiple component analysis I get an indoor air pollution index from different indicators mentioned above. I use the first dimension of the index because the objective is to have a single synthetic index. This dimension represents 23.1% of the total inertia (Figure 3.2). The index obtained varies between -2.82 and 4.07. The higher the index, the worse the indoor air quality. The average index for the sample is 0.21 and the standard deviation is 1.07 (Table A1).

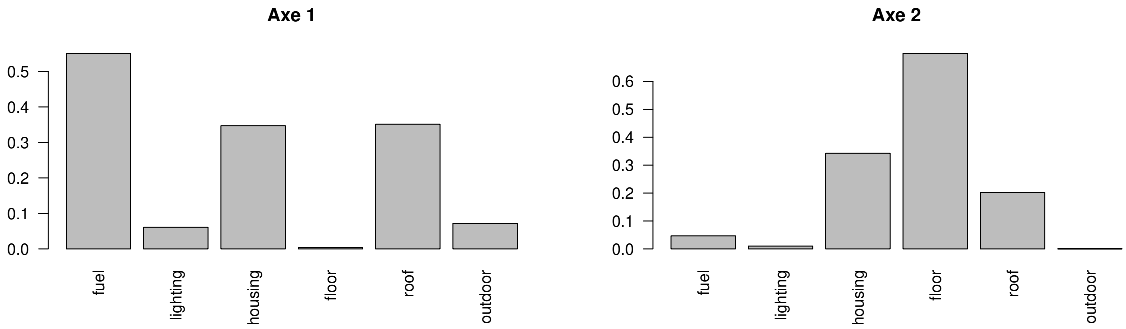
Figure 3.3 represents the overall contribution of each variable in the construction of the axes. The main variables that have a large contribution in the construction of the first axis are the type of fuel, the roof material, the type of dwelling and the level of pollution of the ambient air which contribute respectively to 54%, 36%, 35% to the construction of the first axis.

Figure 3.2: Variances explained by dimensions(%)



Source: Author's own elaboration

Figure 3.3: Contribution to axes construction



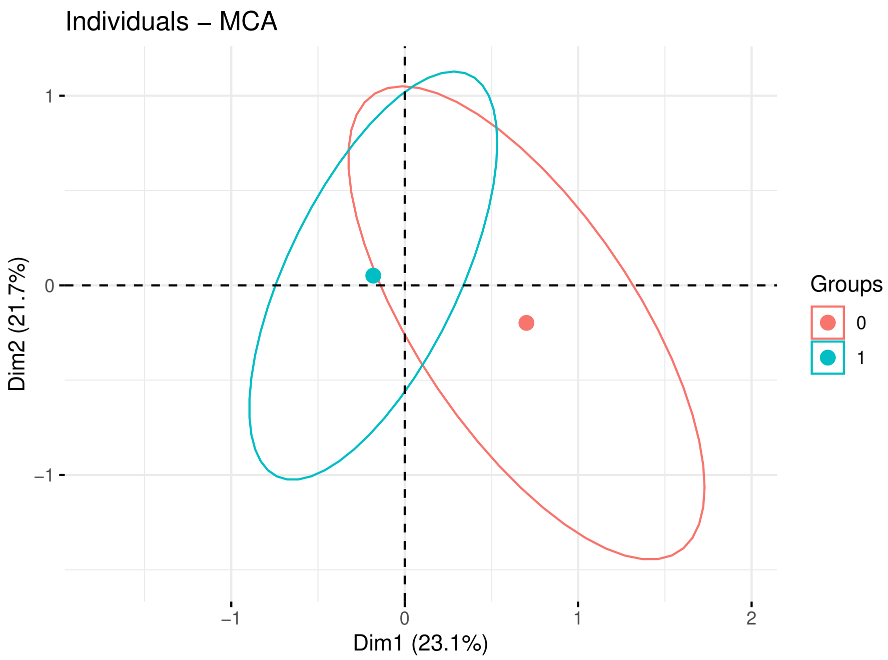
Source: Author's own elaboration

Since the type of fuel is the most important contributing variable in the construction of the first dimension, I make graph 3.4 below which shows the distribution of households along the axes according to the type of cooking fuel. Group 0 corresponds to households that use clean fuel and group 1 to households that use biomass. On the graph, we can see households in group 1 are much closer to the first axis than those in group 0.

3.4 Covariates

Several factors act on the health status of the members of the household. Grossman (1972) through a theoretical modelling of health demand shows that certain demographic and socio-economic characteristics affect the health status of individuals. He shows that each individual is born with a stock of health capital which depreciates with age. Age thus becomes an important determinant of health status. The age of those who consulted ranged from 0 to 99 years, with an average age of about 26 years (Table A1).

Figure 3.4: repartition by fuel type



Source: Author's own elaboration

The age of the head of the household is a very important characteristic that could affect the consumption choices of household members. Through an empirical study on the determinants of the transition to cleaner cooking energy in Ghana, Bofah et al. (2022) find that youth-headed households have a low probability of using dirty energy compared to elderly-headed households in Ghana. The authors explain this by the decrease in income of the elderly head of household. As a result, the household chooses cheaper fuels that unfortunately pollute a lot. To add, the author's result could be explain by the fact that these elderly-headed households do not have information about the harmful effects of using dirty energy.

Gender is an important determinant of exposure to indoor air pollution. Women are not exposed in the same way as men. Indeed, in developing countries, where households generally use biomass as cooking fuel, women spend much more time in the kitchen than men because they are responsible for cooking for the household. As a result, they are more exposed to smoke (Amegah and Jaakkola, 2016).

Furthermore, Grossman (1972) shows that health capital can be maintained through investments in health, more precisely through health expenditure. This expenditure on health depends on the level of income of individuals. The level of income thus becomes an important determinant of health. Indeed, the higher the household income, the more it will be able to spend to preserve its health and thus increase its health capital. In the database, households are divided into five wealth groups, namely very poor, poor, medium, rich and very rich.

Still with the aim of taking into account the financial capacities of the household, I add the gender of the head of household. Indeed, households headed by women are likely to be poorer than those headed by men (Javed and Asif, 2011). This could be due to the fact that these women do not have financial support from a spouse or because they are single, divorced or widowed. In addition, the type of occupation of the head of household is taken into account in the analysis. The type of occupation of the head of household was categorised into three classes which are: agriculture, white collar, and other occupation [5]. Furthermore, the level of education affects the health of individuals (Grossman, 1972, 1976; Thomas et al., 1991; Currie and Gruber, 1996). Indeed, an individual with a certain level of education will be better able to take care of his health because he/she knows what is dangerous for his health or not. These earlier studies show the importance of education. I take this into account in the analysis through the level of education of the individual. The individuals are divided into four education classes: no education, primary education, secondary education and higher education.

Also, the health of one member of the household is produced by all the other members of the household (Jacobson, 2000). Indeed, each member of the family is a producer of his or her own health and that of the others. The influence of other family members in the production of health is important. One palpable case is that of the influence of the mother's level of education on the health of the children (Thomas et al., 1991; Currie and Gruber, 1996). Another tangible example is the negative effect of parental divorce on children's health (Delaney, 1995; Tucker et al., 1997). These studies show the importance of other household members in producing individual health. I take this into account by controlling for household size. Household size ranges from 1 to 34 individuals with an average size of 5 individuals.

4 Stylized facts

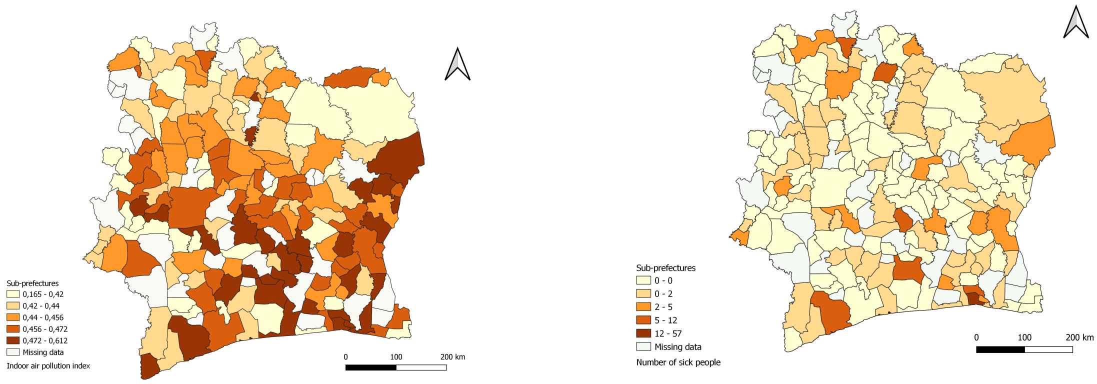
In this section, I investigate the existence of correlation between indoor air quality and health, and the factors that would influence health and the level of indoor air pollution in Côte d'Ivoire.

In graph 3.5, I am interested in the geographical distribution of the level of indoor air pollution and the total number of people who consult for respiratory diseases. A fairly

[5] This class includes, for example, non-agricultural workers, unpaid trainees, domestic staff, self-employed non-agricultural business owners, etc.

high level of indoor air pollution can be observed in most of the sub-prefectures of the country. In addition, in the east, on the border with Ghana and in the centre-south, there is a concentration of sub-prefectures with a fairly high level of indoor air pollution. This would be due to the poor quality of the ambient air in these areas (Figure 3.1). On the other hand, the sub-prefectures located towards the north have the particularity of being less polluted due to the low level of ambient air pollution in this part of the country (Figure 3.1). On the figure 3.5 on the right, there is a distribution of the number of patients by sub-prefecture. Only seven sub-prefectures have a high number of patients. And 5 of these sub-prefectures have a fairly high level of indoor air pollution. Also, a large majority of the sub-prefectures with a high level of indoor air pollution have a very low or even zero number of patients. From graph 3.5, it can be seen that **there is no linear correlation between indoor air quality and the number of sick people at the sub-prefecture level. The effect of indoor air quality on health depends on certain factors related to the sub-prefecture of residence**.

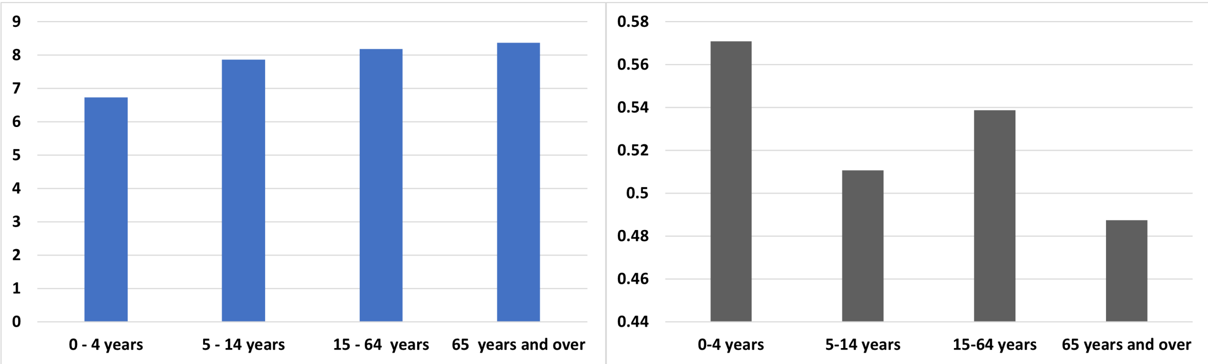
Figure 3.5: Indoor air pollution index (left) and medical consultation (right) by sub-prefectures



Source: Author's own elaboration

To go further, I am interested in the relationship between indoor air quality and the consultation rate for respiratory diseases by age group (graph 3.6). In the left-hand graph, there is a positive correlation between the consultation rate and age. On the left graph, there is no correlation between age and the level of indoor air pollution of the ill persons. The analysis of the two graphs together shows a high consultation rate for people aged 65 and over, although these people live in less polluted housing compared to the other age groups. Subsequently, the age groups 5-14 and 15-64 are characterised by a high consultation rate but the level of indoor air pollution does not follow the same trend in these two groups. For children under 5 years of age, a lower consultation rate can be noticed compared to the other groups, but these children live in a more polluted environment compared to patients of the other age groups. This graph shows the existence of a positive correlation between the consultation rate and the level of indoor air pollution for children under 5. For the other age groups there is no clear linear correlation between the two phenomena. In sum, it can be said that **indoor air pollution is not the only factor explaining the risk of respiratory diseases**.

Figure 3.6: Respiratory disease consultation rate (left) and the average indoor air pollution index (right) by age group



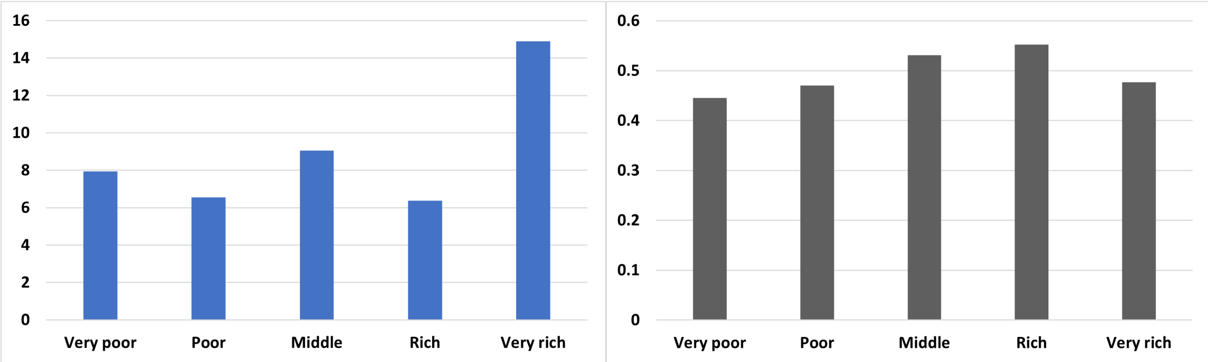
Source: Author's own elaboration

The graph 3.7 shows the relationship between the consultation rate, indoor air pollution and the level of wealth of households. The graph on the left shows that there is no clear correlation between the consultation rate and the level of wealth. Indeed, very poor households have a higher consultation rate than poor and rich households but their consultation rate is lower than that of middle and very rich households. On the other hand, there is a positive correlation between indoor air pollution and wealth. Indeed, in the graph on the right, we can see that the richer the household, the higher the level of pollution. This could be explained by the fact that more than half of the average, rich and very rich households live in urban areas (graph 3.8) where the ambient air quality is generally not good. From the graphs 3.7 and 3.8 we can say that **the level of wealth has little effect on the risk of respiratory diseases. Moreover, the level of indoor air pollution would increase with the level of wealth because of the residential choice**.

The health status of households could be correlated with the level of development of the locality because more development would mean more health services. To verify this, using the night light data, I make a distribution of sick people according to the level of development of the area of residence (graph 3.9). On the graph, we can see that there is no correlation between the level of development and the consultation rate. This could mean that **the level of development of the place of residence has no effect on the risk of respiratory diseases**.

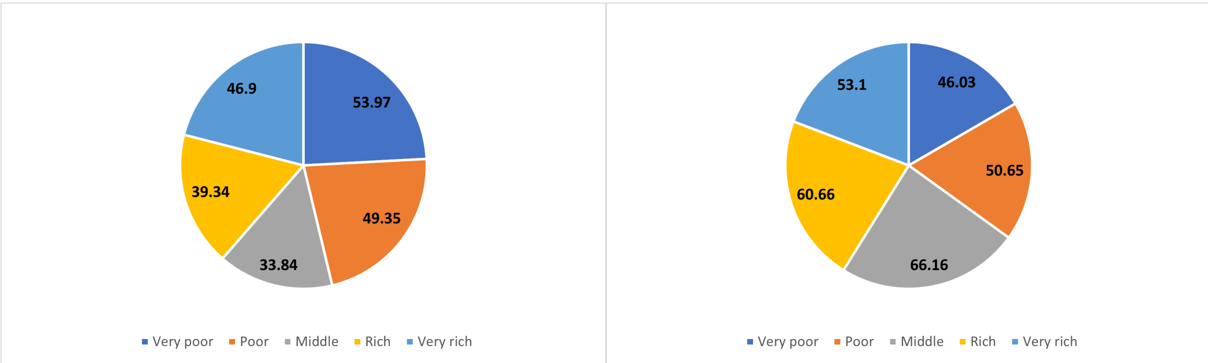
The remainder of the study will focus on econometric analysis to verify the stylized

Figure 3.7: Respiratory disease consultation rate (left) and the average indoor air pollution index (right) by wealth level



Source: Author's own elaboration

Figure 3.8: Distribution of households by wealth group and by rural (left) and urban (right) areas



Source: Author's own elaboration

facts that have just been discovered.

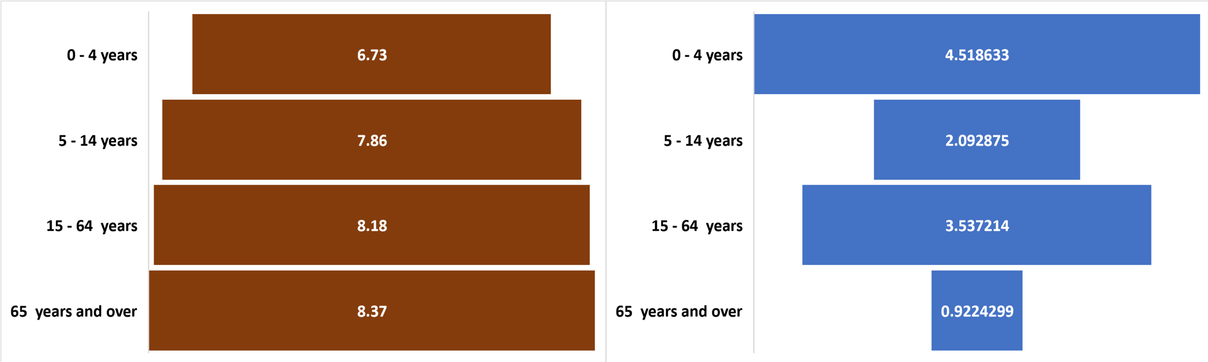
5 Econometric Analysis

This section describes the econometric modelling and the baseline results.

5.1 Econometric modeling

In this study I use a dichotomous model which is a model where the explained variable has two (02) modalities (0 and 1). The modality is 1 when individuals consulted a doctor because of respiratory diseases and 0 otherwise. I can choose between two types of dichotomous models: probit model and logit model. Difference between the two models lies in the mathematical law of the distribution function used. Logistic model uses the distribution function of the logistic distribution while probit model uses the distribution function of the reduced centred normal distribution. These two models provide fairly

Figure 3.9: Consultation rate (left) and sub-prefecture development level (right)



Source: Author's own elaboration

similar results because of the similarities between logistic and the reduced centred normal distribution. On the other hand, logit model has advantages in the interpretation of marginal effects. Furthermore, my data are at 3 levels: sub-prefecture, household and individual. Indeed, beyond the characteristics of each household, several households live in common sub-prefectures. It is important to take into account the "context effects" in order to estimate the impact of the variables without bias. Therefore, for the econometric analysis, I use the multilevel mixed-effects logit model because it allows us to take into account the hierarchical nature of the data. I also add random effects at the household and the sub-prefecture level because this allows to take into account the influence of certain factors at the houshold and sub-prefecture level that may affect the health status of individuals. These factors could be, for example, those that determine households' choice of fuel and the availability of health services at sub-prefecture level.

The likelihood-ratio test is done to evaluate the goodness of fit of the chosen model. The test is done between a model with the control variables and another model without the control variables. The P-value of the test results can be found in the results tables. Furthermore, I calculate the intra-class correlation coefficient (ICC) at the sub-prefecture level and at the household level. The ICC is used in mixed models to give a sense of how much variance is explained by a random effect. It is calculated by dividing the variance of the random effect by the total random variance, i.e. sum of all random effects and error. In the results tables, *"ICC sub-prefecture"* refers to the intra-class correlation at the sub-prefecture level. And *"ICC HH/sub-prefecture"* is the intra-class correlation at the sub-prefecture level with the household. For the case of column 1 of Table 3.3, the *"ICC sub-prefecture"* is 0.04. This means that the random effects of the sub-prefecture make up about 4% of the total residual variance. The *"ICC HH/sub-prefecture"* is 0.238. This means that the random effects of the sub-prefecture and the household make up about 24% of the total residual variance.

5.2 Baseline results

Baseline results (column 2 Table 3.3) show a significant effect of indoor air quality on the risk of respiratory disease in children under 5 years old. An increase in the level of indoor air pollution increases the risk of respiratory diseases by 1.64%. This result is in line with that of studies which found a negative impact of poor indoor air quality on the health status of children in Côte d'Ivoire René et al. (2019); Rosine et al. (2021). This result could be explained by the fact that children at this age spend a lot of time at home and in the company of their mothers. Households that use biomass as fuel are highly exposed to indoor air pollution. Pollutants emitted penetrate the respiratory tract and other human organs, settling in and causing respiratory, cardiovascular and blood diseases.

In the whole sample and the group of people aged between 15-64 years old, being a male significantly increases the risk of respiratory diseases compared to being female (columns 1 & 4 Table 3.3). This result could be explained by the consumption habits of men. Indeed, generally in Africa, men smoke the most compared to women.

Education has a positive marginal effect on the risk of lung disease for individuals aged 15-64 years (column 4 Table 3.3). Indeed, having a higher level of education has a marginal effect of 6.5% on the risk of respiratory disease compared to an individual who has not been to school. This result could be explained by the fact that the vast majority (94.38%) of these individuals live in urban areas that are likely to have high levels of ambient air pollution.

The age of the household head also affects the health status of household members (columns 1 and 4 table3.3). This could mean that as heads of households age, declining incomes force them to make do with relatively cheaper energy options, most of which are unclean.

The fact that the head of the household is male affects the risk of respiratory disease for people aged 65 and over (column 5 Table 3.3). The fact that the head of the household is male has a positive marginal effect of 9.68% on the risk of respiratory disease compared to a female head of household.

Table 3.3: Baseline results

	All sample	0-4 years	5-14 years	15-64 years	65 and over
Indoor air pollution index	0.00254	0.0164***	-0.00806	0.000140	-0.00670
	(0.50)	(3.96)	(-0.35)	(0.03)	(-0.39)
Individual age	0.00560				
	(1.18)				
Individual gender (female)	ref.		ref.	ref.	ref.
Individual gender (male)	0.0186*		-0.0310	0.0341**	0.0209
	(1.80)		(-1.05)	(2.17)	(0.40)
No education (individual)				ref.	ref.
Primary education (individual)				-0.0113	-0.0239
				(-0.59)	(-0.46)
Secondary education (individual)				0.00119	-0.0496
				(0.08)	(-1.28)
Higher education (individual)				0.0650**	0.0605
				(1.97)	(0.65)
Head age	0.00124***	0.000831*	0.000260	0.00194***	-0.00000926
	(3.88)	(1.75)	(0.17)	(3.95)	(-0.01)
Head gender (female)	ref.	ref.	ref.	ref.	ref.
Head gender (male)	0.00919	0.0103	0.0440	-0.0110	0.0968*
	(0.71)	(0.49)	(1.44)	(-0.57)	(1.94)
Agriculture (head)	ref.	ref.	ref.	ref.	ref.
White collar (head)	0.0430**	0.0584	0.0714	0.0350	0.0105
	(2.43)	(1.62)	(1.53)	(1.43)	(0.14)
Other occupation (head)	0.0214	0.0157	0.0619**	0.0173	0.00348
	(1.48)	(0.59)	(2.03)	(0.91)	(0.08)
Wealth	0.0139*	0.0115	-0.00799	0.0107	0.0146
	(1.73)	(0.82)	(-0.33)	(1.02)	(0.46)
Household size	-0.00690	-0.0291	0.00121	-0.00320	-0.0373
	(-0.86)	(-1.26)	(0.03)	(-0.32)	(-1.59)
Observations	2685	639	368	1634	199
Number of houshold	1,001	412	226	785	158
Number of sub-prefectures	170	143	99	161	80
ICC sub-prefecture	.0367908	3.50e-33	8.18e-31	1.64e-31	.0491092
ICC HH/sub-prefecture	.2290265	4.15e-33	.3880053	.1884091	.0491092
LR test P value	0.0000	0.5896	0.4443	0.0000	0.0871

t statistics in parentheses

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

The employment status of the head of household affects the risk of lung disease for the whole sample and for the 5-14 age group (columns 1 & 3 Table 3.3). Indeed, the fact that the head of the household is a white collar worker marginally increases the risk of lung disease by 4.3% compared to a farmer head of household (columns 1 Table 3.3). A likely reason for this result would be that 90.11% of white collar workers reside in urban areas which generally do not have good ambient air quality. For the 5-14 year old group, by a farmer household head, the fact that the household head works in other types of employment has a marginal positive effect of 6.19% on the risk of respiratory disease (columns 3 Table 3.3). For the whole sample, the level of wealth positively affects the risk of respiratory disease (column 1 table 3.3). This result could be explained by the area of residence of rich households and the type of fuel used for cooking. Indeed, according to the data, about 30% of middle, rich and very rich households reside in large cities such as Abidjan, Yamoussokro, Korogho, Bouaké and San-Pedro. And 70% of these households reside in Abidjan. Most of these wealthy households live in areas with poor ambient air quality. In addition, I found that 69.65% of the middle-income and wealthy households use biomass for fuel. As a result, most of these households are exposed to both ambient and indoor air pollution, which would increase the risk of respiratory disease.

The following section provides evidence on the robustness and heterogeneity of the impact of indoor air quality on respiratory disease risk.

6 Robustness checks

The robustness of the results is tested test using a poisson modelling. The dependent variable is the number of people in the household per age group who consulted for respiratory diseases. The results (Table B1) reveal that for children under 5, indoor air pollution positively affects the number of sick people.

In the following lines, I test the non-linearity of the impact as a function of the socio-economic characteristics of the household and of the area of residence.

7 Heterogeneity

The effect could vary according to the socio-economic characteristics of households. In Table 3.4 I focus on children under 5 years old. In columns 1 and 2 Table 3.4, the idea is to see if having older siblings aged between 5 and 15 years in the household could decrease the risk of respiratory diseases by reducing the level of exposure to indoor air pollution. Indeed, older siblings are a source of support for younger siblings (Wikle et al., 2018; Eriksen and Gerstel, 2002). So I suppose a child with older siblings might spend less time with the mother in the kitchen because the older siblings would hold the child while the mother cooks. The results show an opposite effect (column 2 Table 3.4). Having older siblings increases the risk of respiratory diseases. There are two likely reasons for this result. The first reason would be the fuel choice of a household with several children under 15 years oage. Indeed, being a poor household, having several children who cannot yet help financially, leads the household to use a fuel that would be cheaper. Second reason, could be the fact that older siblings are present but do not hold their younger sibling when the mother is cooking because they are also busy doing something else. Furthermore, in columns 3 and 4 (Table 3.4), I am interested in how the impact of indoor air pollution varies with household size. I find that the marginal effect of indoor air pollution remains positive and highly significant only for households above the median size (5 members). The choice of cheaper fuel due to the size of the household added to the lack of financial means could explain this result.

Table 3.4: Heterogeneity by oldest sibling presence and household size

	Have older siblings	Have older siblings	HH size	HH size
	No	yes	<median	>median
Indoor air pollution index	-0.00526	0.0227***	-0.00277	0.0230***
	(-0.67)	(4.46)	(-0.17)	(3.72)
Head age	-0.000658	0.00341***	0.000229	0.000930
	(-1.31)	(2.81)	(0.33)	(1.07)
Head gender (female)	ref.	ref.	ref.	ref.
Head gender (male)	-0.00657	0.0108	0.0310	-0.0425
	(-0.34)	(0.32)	(0.74)	(-0.89)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.00231	0.0703	0.141*	0.0536
	(-0.06)	(1.49)	(1.71)	(1.09)
Other occupation (head)	-0.00858	0.0326	0.0308	0.0138
	(-0.30)	(0.97)	(0.82)	(0.38)
Wealth	-0.00417	0.0301	0.00995	0.00349
	(-0.23)	(1.23)	(0.48)	(0.13)
Household size	0.00463	-0.103*	0.0609	-0.0591
	(0.20)	(-1.70)	(0.65)	(-0.66)
Observations	309	330	278	241
Number of household	228	238	215	171
Number of sub-prefectures	111	109	102	87
ICC sub-prefecture	.5043725	3.15e-34	.1437866	7.68e-37
ICC HH/sub-prefecture	.5043725	6.51e-33	.1437866	4.95e-34
LR test P value	0.9939	0.0420	0.3654	0.8149

t statistics in parentheses

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

Moreover, the place of residence of households modifies their living conditions. Urban areas are more developed in terms of economic activities, public services and, above all, health services are much more developed than in rural areas. Urban households would tend to have better access to health services than rural ones. In addition, the development of economic activity in urban areas could allow households to have a higher standard of living. The results of the Table 3.5 shows that the residence environment has an influence on the impact of indoor air pollution on the risk of respiratory diseases for the whole sample. Indeed, living in a rural area has a marginal positive effect (1.94%) on the risk of respiratory disease (column 3 Table 3.5). This could be explained by the high level of exposure of the rural population to indoor air pollution. In effect, according to the data, 80.59% of less ventilated dwellings are located in rural areas. While a less ventilated dwelling contains a significant amount of pollutants.

Table 3.5: Heterogeneity by milieu

	All sample Urban	15-64years Urban	All sample Rural	15-64years Rural
Indoor air pollution index	-0.00110	-0.00351	0.0194**	0.0274
	(-0.18)	(-0.52)	(2.17)	(1.59)
Individual age	-0.00191		0.0144***	
	(-0.39)		(2.67)	
Individual gender (female)	ref.	ref.	ref.	ref.
Individual gender (male)	0.0178	0.0311	0.0113	0.0308
	(1.58)	(1.57)	(0.63)	(1.18)
No education (individual)		ref.		ref.
		(.)		(.)
Primary education (individual)		-0.0227		0.00673
		(-1.10)		(0.21)
Secondary education (individual)		-0.00528		0.0345
		(-0.30)		(0.93)
Higher education (individual)		0.0750*		0
		(1.90)		(.)
Head age	0.00142***	0.00199***	0.00107**	0.00217***
	(3.76)	(3.37)	(2.14)	(2.60)
Head gender (female)	ref.	ref.	ref.	ref.
Head gender (male)	-0.00914	-0.0253	0.0548***	0.0405
	(-0.43)	(-0.97)	(4.15)	(1.55)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	0.0699***	0.0751**	-0.0285	0
	(2.99)	(2.54)	(-0.99)	(.)
Other occupation (head)	0.0370*	0.0428	0.0315	0.0350
	(1.68)	(1.55)	(1.57)	(1.27)
Wealth	0.0166	0.00547	0.00863	0.0197
	(1.57)	(0.42)	(0.76)	(1.16)
Household size	-0.0140	-0.00734	0.00190	0.00978
	(-1.63)	(-0.74)	(0.14)	(0.47)
Observations	1672	1068	1013	541
Number of houshold	531	438	650	434
Number of sub-prefectures	106	102	147	137
ICC sub-prefecture	.0332444	2.54e-20	.0095087	1.81e-34
ICC HH/sub-prefecture	.2899731	.2072478	.2165138	.122438
LR test P value	0.0000	0.0000	0.0000	0.0060

t statistics in parentheses

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

In order to better capture the level of development of the sub-prefecture, I use night-light data. Table 3.6 shows that the effect of indoor air pollution remains significant only for children under 5 living in the sub-prefectures with a level of development above the median (column 2).

Table 3.6: Heterogeneity by nightlight

	All sample <median	0-4 years <median	15-64 years <median	All sample >median	0-4 years >median	15-64 years >median
Indoor air pollution index	0.000616	0.0273**	-0.0101	0.00488	0.00689	0.00695
	(0.07)	(2.10)	(-0.74)	(0.61)	(1.26)	(1.27)
Individual age	0.0192***			-0.00336		
	(3.08)			(-0.72)		
Individual gender (female)	ref.		ref.	ref.		ref.
Individual gender (male)	0.0247		0.0476**	0.0126		0.0266
	(1.32)		(2.12)	(1.00)		(1.05)
No education (individual)			ref.			ref.
Primary education (individual)			-0.00973			-0.00481
			(-0.36)			(-0.19)
Secondary education (individual)			0.00978			0.00621
			(0.31)			(0.38)
Higher education (individual)			0.0330			0.0749*
			(0.47)			(1.74)
Head age	0.00157***	0.00100	0.00240***	0.00108***	0.000804	0.00175***
	(2.83)	(1.22)	(2.91)	(3.18)	(1.49)	(2.59)
Head gender (female)	ref.	ref.	ref.	ref.	ref.	ref.
Head gender (male)	-0.00612	0.00118	-0.0467	0.0117	0.0241	-0.000387
	(-0.25)	(0.05)	(-1.15)	(0.89)	(0.79)	(-0.02)
Agriculture (head)	ref.	ref.	ref.	ref.	ref.	ref.
White collar (head)	0.0494	0.0523	0.0396	0.0427	0.0625	0.0317
	(1.64)	(0.65)	(0.96)	(1.61)	(1.59)	(0.76)
Other occupation (head)	0.0316*	-0.0215	0.0280	0.0177	0.0421	0.00475
	(1.72)	(-1.14)	(1.16)	(0.77)	(1.01)	(0.13)
Wealth	0.00447	-0.0257*	0.0150	0.0214**	0.0492**	0.00757
	(0.37)	(-1.79)	(0.93)	(2.18)	(2.53)	(0.45)
Household size	0.00586	-0.0449	-0.00216	-0.0136**	-0.0204	-0.00345
	(0.40)	(-1.40)	(-0.11)	(-2.14)	(-0.57)	(-0.37)
Observations	1068	286	636	1617	353	998
Number of houshold	606	233	456	395	179	329
Number of sub-prefectures	115	93	108	55	50	53
ICC sub-prefecture	.0410572	2.91e-33	8.06e-34	.0323717	9.19e-34	9.41e-27
ICC HH/sub-prefecture	.3111397	3.05e-33	.4373947	.1455135	1.52e-32	.0745
LR test P value	0.0000	0.1867	0.0163	0.0000	.	0.0006

t statistics in parentheses

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

8 Conclusion

In Côte d'Ivoire, as in most developing countries, a large majority of population is exposed to poor indoor air quality. This is mainly due to the fuel used, especially biomass fuels, which emit pollutants that are toxic to human health. In our sample 87.20% of households use biomass as fuel because it is the most affordable type of fuel.

This study looks at the effect of indoor air pollution on different age groups in Côte d'Ivoire. The results obtained are in line with the existing literature (Padhi and Padhy, 2008; Edwards and Langpap, 2012; Ranathunga et al., 2019; René et al., 2019; Basu et al., 2020; Kinney et al., 2021). Indeed, indoor air pollution increase the risk of respiratory diseases in vulnerable children under 5 years old. Moreover, the marginal effect of indoor air pollution varies according to the characteristics of the household, the area of residence and the level of development of the sub-prefecture. Furthermore, several factors such as the gender and education level of the individual, the age and occupation of the household head, and the level of household wealth affect the respiratory health of the household members.

In order to achieve Sustainable Development Goal 7, which is to ensure access to affordable, reliable, sustainable and modern energy for all, it would be important for Côte d'Ivoire to ensure the implementation of the PANER. This could be done by raising awareness among the population about the harmful effects of indoor air pollution caused largely by the use of solid fuel, as the pollutants emitted as a result of the poor combustion of biomass are very dangerous for human health, especially that of children, women and elderly. Mothers could be made aware of the need to keep children away from cooking areas in order to protect them from the smoke emitted and also the need to air the houses very well regularly. To do this, public decision-makers must set up education and prevention programmes on the risks associated with the use of solid fuels, in schools, maternity wards, etc. In order to limit the use of biomass, another recommendation would be to subsidise the purchase of gas stoves so that they are accessible to the population, as poverty is a major determinant of the choice of cooking fuel (Ouedraogo, 2006; Bofah et al., 2022; Zhou et al., 2022). This would encourage households to use less polluting fuels such as butane gas. Furthermore, Ivorian public policymakers could provide the population with stoves that can burn all types of biomass cleanly and encourage Ivorian households to use them. These include the Ultra-Clean Biomass Cookstove, Mimi Moto forced air gasifier stove and Shengzhou Charcoal Stove[6]. In addition, the government should promote the introduction and use of renewable energy as a fuel by households.

[6]https://www.who.int/tools/clean-household-energy-solutions-toolkit/module-7-defining-clean

Like any study, this one has limitations. The first limitation is that the PM2.5 concentration level I use to approximate ambient air quality is an annual data. It would have been interesting to have the PM2.5 level a few months or weeks before the survey. The second is that I do not have the exact geographical location of the households. This information could allow me to better quantify the PM2.5 concentration of the ambient air to which the household is exposed.

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Appendices

A Descriptive statistics

Table A1: Descriptive statistics

Variable	Observations	Mean	Std. dev.	Min	Max
Sick people	2,862	0.0782669	0.2686381	0	1
Indoor air pollution index	2,862	0.2088955	1.065497	-2.823349	4.071756
Age	2,805	25.52086	20.80195	0	99
Gender	2,862	0.4350105	0.495845	0	1
Education level	2,401	0.4760516	0.4995302	0	1
Head age	2,861	42.96994	14.0855	16	120
Head education level	2,862	0.5527603	0.4972954	0	1
Wealth group	2,862	1.444444	0.7021878	0	4
Household size	2,862	4.992662	2.937592	1	34

B Robustness checks

Table B1: Poisson model

	All	0-4 years	5-14 years	15-64 years	65 and over
Indoor air pollution index	0.00534	0.0148**	-0.0127	-0.0131	-0.00709
	(0.54)	(2.01)	(-0.56)	(-1.08)	(-0.49)
Individual age	0.00459				
	(0.61)				
Individual gender (female)	ref.		ref.	ref.	ref.
Individual gender (male)	0.0284		-0.0697**	0.0491*	0.0200
	(1.25)		(-2.18)	(1.92)	(0.35)
No education (individual)				ref.	ref.
Primary education (individual)				0.0220	-0.0240
				(0.75)	(-0.48)
Secondary education (individual)				0.0379	-0.0483
				(1.33)	(-1.01)
Higher education (individual)				0.166**	0.0496
				(2.31)	(0.55)
Head age	0.00319***	0.00103	0.000936	0.00406***	-0.00000981
	(5.10)	(1.59)	(0.71)	(5.39)	(-0.01)
Head gender (female)	ref.	ref.	ref.	ref.	ref.
Head gender (male)	0.0385*	0.00365	0.0455	0.00350	0.0967**
	(1.74)	(0.13)	(1.34)	(0.13)	(2.14)
Agriculture (head)	ref.	ref.	ref.	ref.	ref.
White collar (head)	0.213***	0.0659	0.0628	0.165***	-0.000873
	(3.88)	(1.43)	(1.64)	(2.86)	(-0.01)
Other occupation (head)	0.0701***	0.0175	0.108***	0.0406**	0.00388
	(3.70)	(0.73)	(3.25)	(2.03)	(0.08)
Wealth	0.00450	0.00982	0.00312	-0.0168	0.0126
	(0.29)	(0.56)	(0.18)	(-0.77)	(0.37)
Household size	0.0721***	-0.0248	0.0292	0.0553***	-0.0367
	(4.01)	(-0.91)	(0.78)	(2.81)	(-1.52)
Observations	2685	639	368	1634	199
LR test P value	0.0000	0.6659	0.0307	0.0000	0.0987

t statistics in parentheses

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

Chapter 4

Does particulate matter pollution affect school attendance in South Africa?

1 Introduction

According to World Health Organization, more than 90 per cent of people live in a place that does not meet air quality standards, and the part of the world exposed to particulate pollution is mostly made up of developing countries (?). The greatest environmental risk on the African continent is air pollution (THE BORGEN PROJECT, 2020). In particular, South Africa is one of the most polluted countries in the world in 2019 (IQAIR, 2020). Two types of pollution undermine the South African environment : air pollution and marine pollution. The first source of air pollution is the industrial sector. This is because South Africa is a newly industrialised country according to the World Bank and has a relatively large contribution of its industrial sector to the national GDP. It ranks 33rd in the world in terms of GDP, has a diversified industrial sector. And then, its manufacturing sector is dominated by agriprocessing industry, automotive industry, chemicals industry, Information and Communications Technology and electronics industries, metals industry, textiles and clothing and footwear industry. The development of the sector explains the high level of pollution in the country. The energy mix could also explain the country's air pollution levels. Indeed, most of the energy consumed is generated by coal and oil (Ritchie et al., 2022). In 2022, coal will account for 70% of primary energy (Ritchie et al., 2022).

Regarding this situation South African government put in place 2004 Air quality act which is a law for air quality management including control at the source until its impact on people. The Act has established a list of pollutants and polluting activities, which has resulted in the establishment of certain standards. In 2009, emission limits were set for sulphur dioxide (SO2), nitrogen dioxide (NO2), particles with an aerodynamic diameter of less than 10 microns metres (PM10), ozone (O3), benzene (C6H6) and lead (Pb). Then, in view of the adverse public health effects of fine particulate matter (PM2.5), these are added to the list in 2012. In 2013, the list of highly polluting activities includes 10 categories of activities which are combustion installations, petroleum industries, carbonization and gasification, metallurgical industry, mineral processing, storage and handling, organic chemicals industries, inorganic chemicals industries, thermal treatment of hazardous and general waste, pulp and paper manufacturing industries, and animal matter processing with emission limits defined for each.

The environmental efficiency of South Africa's regulation on air quality depends on its impact on health and more specifically on human capital. The objective of this study is to study the impact of air pollution on one of the most vulnerable individuals : children. Indeed, children are more exposed to pollution because of their height since pollutants are more concentrated at one (01) meter than at two (02) meters from the ground (Umwelthilfe, 2019) and early exposure air to pollution has more damaging effects (Pope III, 2002).

PM 2.5 from anthropogenic or natural sources is very harmful to human health and the cause of mortality from respiratory and cardiovascular diseases (Kampa and Castanas, 2008). By affecting human health, it can affect economic performance of countries through its impact on human capital. In this study, I am particularly interested in the relationship between air pollution and school absenteeism. Previous studies test the link between particulate pollution and school absenteeism and find a mixed effect. The impact may be positive (Ransom and Pope III, 1992; Makino, 2000; Park et al., 2002; Ransom and Pope, 2013; MacNaughton et al., 2017), negative (Chen et al., 2000) or null (Gilliland et al., 2001; Rondeau et al., 2005).

This study differs from the previous ones in two ways. First difference is the sample. Contrary to the previous studies, this study focuses on an African developing country which is one of the most polluted by PM2.5 in the world (?) and with less regulation. The absence of African countries as a sample in this literature could be explained by the absence or poor quality of the data (Kalisa et al., 2023). The second distinction concerns the methodology used. The choice of residence supposedly leads to a non-random distribution of exposure to air pollution. As a result, PM2.5 concentration is potentially subject to an endogeneity bias. Another originality of this study is to take into account this endogeneity bias using control function method of Wooldridge (2015) which is similar to two stage least squares (2SLS) approach but with some interesting advantages over 2SLS. The question this study is trying to answer is what is the effect of PM exposure on school absenteeism. The interest of this study is to help us to better understand the impact of air pollution on school attendance in an African developing country.

In order to answer our research question, we use data from the General Household Survey of South Africa over the period 2015-2016. The variable of interest is constructed using data from van Donkelaar et al. (2018). This study is the first to use these data to study the relationship between particulate pollution and school absenteeism. Using a random effects logit model and an instrumental variable method, results show an increase in PM2.5 concentration by 10 $\mu g/m^3$ results in a 1.33 to 2.46 percent risk of absenteeism. However, the impact depends on individual and household characteristics.

The next section reviews the existing literature. Data, stylized facts and hypotheses are presented in the third section. The fourth section describes the econometric analysis. Then, the fifth and sixth sections deal respectively with the transmission channels and robustness checks. Section 7 shows heterogeneity of the impact. The last part discusses conclusion and policy implications.

2 Background

This section provides a summary of the literature on the characteristics of the South African education system, the determinants of school absenteeism in South Africa, the relationship between air pollution and health and the impact of air pollution on school absenteeism .

2.1 South African Education System

"Apartheid" introduced in 1948 and abolished on June 30, 1991 did not spare the South African education system. Indeed, this policy of "separate development" led to a division and unequal distribution of the educational system by skin color (the "blacks" on one side and the "whites" on the other) (Vambe, 2005). This unequal educational system trained children differently because training programs differed according to the positions that child is expected to have in social, economic and political life in the future. As a result, best training programs were reserved for "whites" (Education Department, 2002). Immediately after apartheid, South African government introduced a unique educational program to reduce educational inequalities created during racial segregation (Education Department, 2002).

After the election of Jacob Zuma as president in 2009, the Ministry of Education was split in two. South African education sector is now shared between the Ministry of Basic Education and the Ministry of Higher Education and Training. The education system is divided into three successive levels of education: primary education, secondary education and tertiary education. Primary students are aged between 7 and 15 years old. In 2001, the average age of admission to grade 1 was set at 7 years by the Education Department (Education Department, 2001). As in most countries, in South Africa the private sector also provides educational services.

In addition, there are major geographical inequalities in the education system. In 2007, 41% of rural students in grade 6 which is the exit-level of the Intermediate Phase, performed poorer compared to 13% of students of the same level who live in cities. In addition to the inequalities within the country, grade 6 students have a lower level of education than those in Kenya or Tanzania for example (Spaull, 2015). Furthermore, school dropout is not negligible. For example, in 2014, about 50% (532,860) of the students in the cohort took exams (Matric (grade 12)) while there were 1,085,570 students enrolled in the 12-year old cohort, i.e. in grade 1 (Spaull, 2015). This school dropout is mainly related to financial constraints and pregnancy, which explains 50% of the dropout rate among girls (Gustafsson et al., 2011).

The Ministry of "Basic Education" has put in place various policies that would allow the proper functioning and efficiency of the education system. First, since the health status of students is paramount for their academic success, policies have been put in place to reduce the negative effects of diseases such as HIV, tuberculosis and sexually-transmitted infections on learners (students), educators and all those working in schools (Basic Education Department, 2017a) . These policies aim to improve the academic achievement of students in a health context weakened by HIV, sexually-transmitted infections and tuberculosis. Also, punishment in the context of school learning, the Ministry of Basic Education is implementing a protocol regarding corporal punishment. This protocol prohibits corporal punishment and provides guidance to schools, provinces, and districts on how to deal with issues related to corporal punishment (Basic Education Department, 2017b). Then, policies implemented since 2001 include the Integrated Quality Management System (IQMS), which aims to contribute to the professional development of teachers. The goal is to improve learning in schools (Mestry et al., 2009). Furthermore, in 1995, in order to maintain a healthy working environment for teachers, the Department of Labour set up an Education and Labour Relations Board. The primary goal is to maintain and promote labour peace in education (Labour Department, 1995). According to a joint study by International Labour Organization and UNESCO, the Education and Labor Relations Board is a framework for social dialogue. Only African countries such as Namibia and South Africa have been able to set up this kind of institution to promote social dialogue (**?**). In addition, in order to improve academic and social conditions of learners, the Ministry of Basic Education is putting in place indicators to determine whether a learner is a victim of sexual, drug or alcohol abuse (The Education Labour Relations Council, 2003).

According to literature, South African education system is structured with policies in place to provide a healthy working environment for teachers and learners. Unfortunately, these policies are insufficient in terms of health protection against environmental degradation and more specifically air pollution. One of the main objectives of our study would be to draw the attention of South African policy-makers to the importance of air quality that students breathe and its adverse health effects that affect their school performance.

There are several factors that could explain absenteeism and the following section gives an idea of the determinants of truancy in South Africa.

2.2 Determinants of school absenteeism and performance in South Africa

School absenteeism has several drivers at both the social and economic levels. First, poverty is an important determinant. Authors such as Adato et al. (2016) study the effect of cash transfers on school participation in South Africa. They use the Child Support Grant program as a proxy for cash transfers. The goal of this subsidy program for poor households with young children is to provide social protection and reduce poverty and inequality between rich and poor children in terms of nutrition and to reduce early pregnancy and risky sexual behavior. Their results show that having a scholarship has a positive but partial effect on students' school participation. The effect of poverty on school performance is also proven by Hunter and May (2003). The authors add that this is a controversial determinant because a family's poverty level can push it to keep the child in school because the child represents family's future. That is the only asset that the family holds. Timæus et al. (2013) based on data from "the National Income Dynamics Study" collected at the community level in 2008 also show that the household poverty level also determines children's school participation. In this study we don't use income level of households as control because of potential endogeneity bias the child's absence could be due to the fact that he or she is working and thus generating income for the household.

Furthermore, a second determinant of school performance in South Africa is the presence of biological parents in the household. The death of one of the biological parents, especially the mother, has a negative impact on children's school performance. In a study conducted in the province of KwaZulu Natal, Case and Ardington (2006) show that the death of a father or mother has a different impact on school performance. Maternal orphans appear to perform poorly academically compared to other children their age whose mothers are alive. They are also less likely to be enrolled in school and to complete several years of schooling. Paternal death has no significant effect on the child's school performance. According to Operario et al. (2008), the effect of parental death differs depending on whether the child is a girl or a boy. Their study shows that the absence of the mother or father has a greater effect on the schooling of girls than boys. The study finds that orphan girls are less likely to complete school than orphans after controlling for household poverty level. Timaeus and Boler (2007) find maternal absence does not significantly affect a child's school performance. On the other hand, paternal absence has an effect. This can be explained by the fact that paternal absence could affect the household's poverty level.

In addition, mother's level of education has a positive effect on the child's academic success in South Africa (Timaeus and Boler, 2007; Timæus et al., 2013; Visser et al., 2015). A well-educated mother is more likely to get her children into school. Indeed, parents with a high level of education value education more and consider education as a good way to succeed in life. Therefore, they monitor child's school education. In other words, this kind of parent is more involved in the child's academic success.

Also, school resources made available to students determine their success at school (Case and Deaton, 1999; Visser et al., 2015). Socio-economic factors such as the pupil-teacher ratio, which is the ratio of the number of pupils to the number of teachers, and the size of classes have a significant impact on pupils' schooling and academic results.

Health and nutrition profile of students is an important determinant of school performance in Nelson Mandela's country (Jinabhai et al., 2001). Findings from the study reveal micronutrient deficiencies, parasitic infections, and stunting remain significant problems among school-aged children in rural South Africa. Addressing these problems would promote children's health and education. In addition, school tardiness is a major determinant of school dropout (Branson et al., 2014). Indeed, repeating or resuming classes pushes some students to drop out of school for good.

To better understand the channel through which air pollution affects school absenteeism, it is very important to focus on the effects of air pollution on human health. This is the objective of the following section.

2.3 Local air pollution and health outcomes

Air pollution is a serious but neglected problem in Africa (Tanmowo, 2000) and is among the main causes for death in Africa (Bauer et al., 2019). The main sources of pollution include road traffic, industrial activities, biomass burning (Petkova et al., 2013). In recent decades, researchers are beginning to focus on its effects on the African population living in the most vulnerable countries due to the lack of good pollution regulation policies. The impacts on health are not negligible. The majority of researchers are interested in the health impacts of this atmospheric deterioration in Africa. This degradation of air quality affects life expectancy, causes cardiovascular diseases and mortality (Lelieveld et al., 2018; Noubiap et al., 2015; Mustapha et al., 2011). Bauer et al. (2019) looks at the effects of air pollution on mortality in Africa according to the sources of pollution (natural, industrial or domestic and biomass combustion). The results show that about 43,000 premature deaths in Africa are related to biomass burning due to agriculture in 2016. In South Africa and Nigeria, the high mortality rate due to pollution is explained by the industrial sector (Bauer et al., 2019).

Furthermore, Roy (2016) looks at the significant economic cost to Africa of ambient particulate pollution. In particular, the economic cost related to premature deaths. Indeed, the number of premature deaths as a result of ambient pollution increased by 36% between 1990 and 2013, and those related to household pollution increased by 18% over the same period. The estimated economic cost of premature deaths due to ambient particulate air pollution is around 215 billion US dollars and the cost due to household air pollution is around 232 billion US dollars.

Air pollution has important health effects on the South African population. It causes respiratory diseases, cerebrovascular (Wichmann and Voyi, 2012) and acute respiratory diseases in children (Barnes et al., 2009). Most of the studies done on the subject in South Africa link (indoor) air pollution to the source of energy used by the households. These studies show that the use of solid fuels (Barnes et al., 2009; Norman et al., 2007; Röllin et al., 2004; Vanker et al., 2015) or tobacco (Elf et al., 2017) leads to an increase in the level of indoor pollution which results in respiratory diseases. In 2007, Norman et al. (2007) investigate the relationship between indoor pollution from solid fuel use and respiratory disease in South Africa. The study finds that about 20% of South African households are exposed to indoor pollution from heavy fuel use. This pollution is responsible for 0.5% of deaths in the country. It also leads to a 0.4% increase in the loss of healthy life years. Röllin et al. (2004) investigates the relationship between rural electrification and indoor pollution in South African villages. The results show that non-electrified houses had an average daily particulate concentration level of 162 $\mu g/m^3$ compared to an average pollution of 77 $\mu g/m^3$ in electrified houses.

Aware of the level of pollution in the country, South African authorities have put in place policies and interventions to reduce the health costs of air pollution. The results of Leiman et al. (2007) show interventions at the household level are more effective than interventions at the industrial level. The authors conclude that addressing the health costs of air pollution in South Africa should start with addressing the household rather than industrial sources of pollution. Thambiran and Diab (2011) proposes a double benefit policy in terms of reducing pollutants and greenhouse gases. These policies are the reduction of the number of kilometers driven by private motor vehicles and the improvement of the efficiency of road freight transport. Katoto et al. (2019) and Coker and Kizito (2018) through a critical analysis of studies already done on the subject, conclude that the negative health effects of air pollution are under-researched in Sub-Saharan Africa compared to other continents because of a lack of air quality monitoring and epidemiological studies on air pollution, and because of the population's considerable vulnerability.

In view of this abundant literature on Africa, there is less literature on one dimension of human capital, namely education and educational performance. This study aims to fill this gap by examining the relationship between air pollution and educational performance in South Africa. While health is important for good human capital, education also matters.

The following section focuses on the results of previous studies regarding the impact of air pollution on school absenteeism.

2.4 Air pollution and school absenteeism

There is a vast literature on the relationship between suspended particulate pollution and school absenteeism and most of this literature focuses on developed countries. Considering the USA, Ransom and Pope III (1992) investigated the effect of PM10 on school attendance in an elementary school. The results show a positive effect of PM10 on weekly and daily school absenteeism. In a similar vein, Makino (2000) studied the impact of suspended particulate matter on the daily absence of schoolchildren in Japan between 1993 and 1997. The authors find that suspended particulate matter positively affects school absenteeism. Also, Park et al. (2002) finds a positive effect of PM10 on illness-related school absenteeism in Seoul between March 1996 and December 1999. Ransom and Pope (2013); MacNaughton et al. (2017) also find a positive effect of PM10 and PM2.5 on school attendance in the United States of America. The various authors explain the positive impact of air pollution on school absenteeism through the illnesses that exposure to air pollution causes. As a result, some sick pupils are unable to attend school.

Contrary to our intuition, in the literature, the effect of air pollution on school absenteeism is not always positive. For example, Chen et al. (2000) on a sample of 57 elementary schools in the United States of America between 1996 and 1998, found that PM10 negatively affected school absenteeism. In contrast, another group of authors found that particulate air pollution had no effect on school absenteeism. Using a sample of 2081 students, Gilliland et al. (2001) found a non-significant effect of PM10 exposure on school absenteeism in California in 1996. Similarly, Rondeau et al. (2005) investigated the impact of PM10 on the daily absence of 1932 pupils aged between 9 and 10 in California. The results show that PM10 exposure has no effect on children's daily school absenteeism.

The conclusion of the economic literature on the subject is that the impact of suspended particulates on school absenteeism is mixed. The effect can be positive, negative or nil. This study will contribute to the debate on the subject. The Table A1 in the appendix provides a brief summary of these studies.

3 Data and stylized facts

This study combines household survey data with satellite data of fine particles. In this section are described the databases, the variables used and the stylised facts obtained from the data.

3.1 Data

Panel data over 2 years, 2015 and 2016 are used. The data come from the general household survey (Statistics South Africa, 2016, 2015), a typical household survey conducted approximately every year throughout South Africa. This survey provides information about socio-economic characteristics, health, education, general functioning and social security of South African households. Data is available at provincial level, so there is no information on the location of households at a finer level.

These survey data offer several advantages. They better describe the relative characteristics of the South African population. First, they enable the collection of data that are close to the exact characteristics of the general population. Second, thanks to the high representativeness of the population, survey data enable us to obtain statistically significant results compared with other methods of data collection. These databases also allow us to have several variables at our disposal for analysis.

To these survey data is added the satellite database of van Donkelaar et al. (2018) which contains information on the average level of PM2.5 concentration in the South African provinces. The two databases were merged using information on households' province of residence and provide information on local pollution in South Africa. The joint use of these databases is advantageous on several levels. First, it allows a better understanding of the different aspects and impacts of air pollution on the local population. Second, it provides information on whether or not there is heterogeneity of impacts according to provinces and the socio-economic status of households.

In addition, several reasons explain the choice of study period. The first is the availability of data to exploit the panel structure and South African authorities started to survey the same households every year from 2015. Because of temporal dimension of the interest variable (1998-2016) we are obliged to limit the study to a period of 2 years. The explained variable is a dichotomous variable that takes 1 if the child was absent during the previous school week and 0 otherwise. This variable is the response to the question "Has... been absent from school during the past school calendar week (Monday to Friday) ?", with four (04) possible responses which are "Yes", "No", "Do not know" and "Not applicable - school closed e.g. school holiday". Thus, explained variable is reconstructed from raw data obtained from these answers. Overall, there is a higher level of absenteeism in 2015 compared to 2016. In fact, on graph 4.1 1202 people were absent in 2015 compared to 1078 people in 2016. There is also an uneven distribution of absences within provinces by year. In 2015, KwaZulu Natal stands out from the other provinces with a high number of people absent.

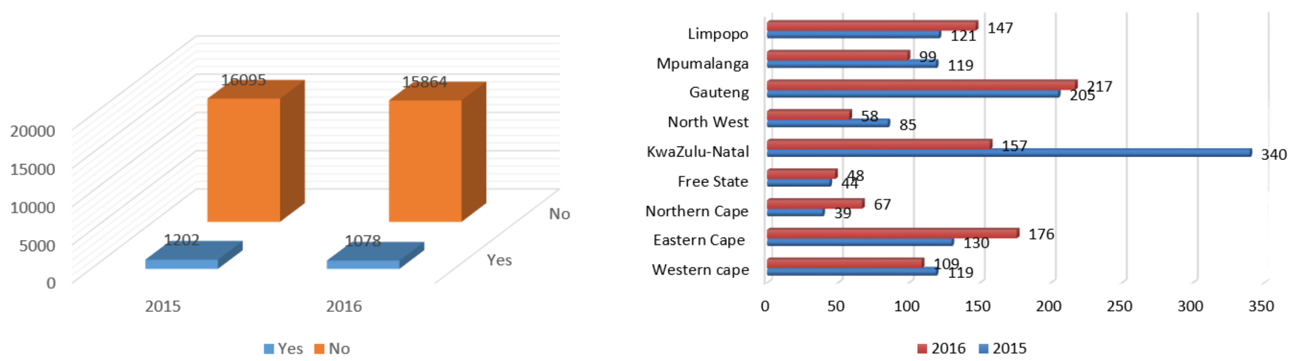

Figure 4.1: Absenteeism by year (on the left) and province (on the right)

Pollution variable used is a continuous quantitative variable. It measures the annual average concentration of fine particulate matter in $\mu g/m^3$ per province and is taken from the van Donkelaar et al. (2018) database. This is satellite data and extracted using QGIS software. Over the study period and throughout the country, the average pollution is 117.47 $\mu g/m^3$ with a dispersion from the average of 67.45 $\mu g/m^3$. The minimal pollution is 16.06 $\mu g/m^3$ and is registered in the Western Cape province in 2016. On the other hand, the maximum pollution is 221.42 $\mu g/m^3$. It is registered in Gauteng province in 2015. These average annual concentrations of PM2.5 far exceed the WHO recommendation of 5 $\mu g/m^3$.

Age, gender of the individual, gender of the household head and his or her level of education, household wealth index, household size, presence of biological parents in the household, lack of teacher, travel time between home and school, rainfall and annual relative humidity are used as control variables.

Individual's age is a very important control variable. Indeed, as the child's age increases, the more likely he or she is to be able to engage in other income-generating activities and the more likely it is to be absent from school. Also, the older the child gets, the less the parents become involved in the child's school affairs. The child could therefore take advantage of this lack of parental supervision to truant.

In addition, the presence of gender in the study matters (Currie et al., 2009). In some African countries, girls are less educated than boys. This discrimination could be a determining factor in school absenteeism and early pregnancy for girls (Spaull, 2015).

The characteristics of the household head help to understand child's behaviours. Education level of the household head could influence his or her interest in school. Household head education level is therefore expected to have a negative effect on the child's school absenteeism. Household head gender is also important because it gives a signal on the financial capacities of the household.

Also, we add information on household's characteristics such as household wealth, household size and biological parents presence in the household. In effect, household size could help us understand the living conditions of child. And then, the presence of the biological parents would indicate whether there is someone caring for the child (Case and Paxson, 2001) or concerned about the child's academic performance.

The level of wealth index permits to approximate socio-economic status of the household. Since information on household total income is not usable. Indeed information on household income is declared data, and may therefore be biased. This is why we use an index based on the characteristics of household assets. The index is constructed from variables that inform on the economic status of the household (Rustein and Johnson, 2004). Information on the type of dwelling, access to electricity, presence of a household helper and the ownership of a vehicle, TV, DVD, air conditionner, computer, dish machin, wash machin and refrigerator are used. Principal component analysis method is used to synthesize all the information and create an index. According to the Kaiser Guttman rule (KG rule), two axes have an eigenvalue greater than 1 (Figure D1 and D2 in appendix D) but we keep the first axis which contains 35% of the total inertia. This means that this axis accounts for the greatest percentage of the total variation in the data used. The wealth index allows us to take into account the living conditions of the household, which is very important in understanding the reasons for the absence of individuals from school (Behrman, 1996; Currie et al., 2009). Wealthy households could require the child to stay at home in case of pollution peaks in order to avoid exposure to pollution. Also, a wealthy household could choose to elect its residence in a non-polluted area. As a result, poor households are the most exposed.

In addition, commuting time to school and lack of teachers are factors that could influence student absenteeism. The further away the home is from school, the less incentive there is to attend. This is also the case with the lack of teachers.

Futhermore, meteorological conditions such as *rainfall and relative humidity* are important in this study. In fact, the weather can have a direct impact on school absenteeism. Bad weather conditions, such as storms, can prevent pupils from attending school. Also weather could impact the likelihood of individuals attending school. Weather impacts through the diseases that bad weather conditions could cause (Currie et al., 2009; Lepeule et al., 2018). And when pupils get sick, some can not attend school either because they stay at home or are hospitalized.

3.2 Stylized Facts

Pollution is an unrecognized silent killer in Africa (Abera et al., 2020). According to the World Bank, poor air quality is responsible for 20,000 premature deaths each year in the country with an economic cost of R300-million (journal, 2016). South Africa is a country with nine provinces whose most polluted are Gauteng, Mpumalanga, North West and Limpopo, Free State and Kwazulu-Natal (Figures 4.2 and 4.3) on study period. The high level of air pollution in Gauteng, Mpumalanga and Limpopo can be explained by the presence of coal-fired power stations.

Also, the high level of particulate pollution would be due to the high level of economic activity in these regions, and more specifically manufacturing activity. Indeed, four of the most polluted provinces are part of the country's top six economic hubs. These are the provinces of Gauteng, Kwazulu-Natal, Mpumalanga and Limpopo. In 2018, these provinces contributed respectively 34.94%, 16.04%, 7.24% and 7.18% to the national GDP (INSIGHTS, 2020). These areas have a very important economic weight for the country. Apart from the fact that the country is the manufacturing hub of Africa, it also has the most industrialized and diversified economy on the continent. Moreover, talking about industries automatically reminds us of one of its side effects, which is pollution. The most economically active provinces are those that emit more pollutants into the atmosphere via road traffic and/or the industrial sector, which are among the main sources of pollution. The manufacturing sector is the largest source of air pollution in South Africa. In addition, there is the growing urbanisation of certain regions and the neighbourhood effect. The North West Province is one of the most polluted provinces not only because of its proximity to Gauteng but also because of the mining activities in the province. Mining operations are accelerating the rise of pollution in some parts of the country.

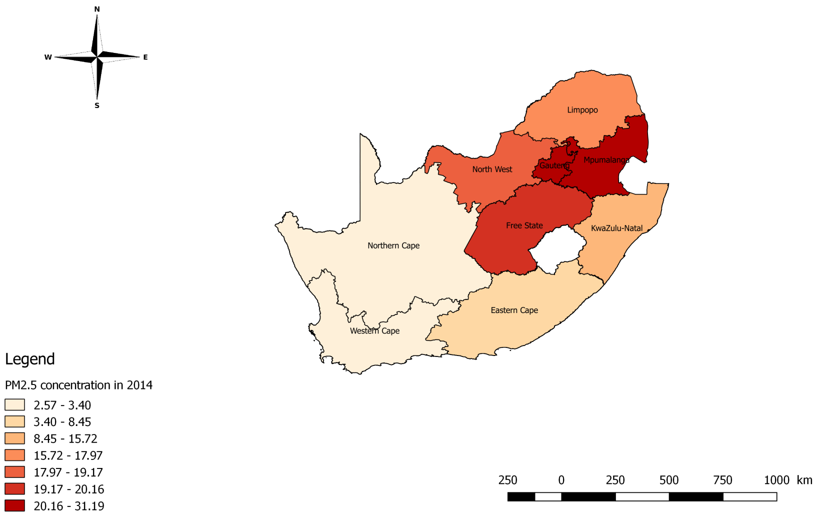

Figure 4.2: Air pollution in 2014
Source: Author's own elaboration

According to Greenpeace, NASA satellites data ranks Kriel area in Mpumalanga as second worst sulphur dioxide (SO2) emission hotspot in the world (Greenpeace, 2019). This high level of sulfur dioxide is due to its coal industry. Indeed, by constituting 92% of energy production and 74.3% of primary energy consumption, coal dominated the energy sector in 2017 and the country was the 3rd largest coal producer in the world in 2018. Sulfur dioxide is very harmfull for human health and contributes to the formation of fine particulate matter (PM 2.5). It can lead to respiratory infections, stroke, diabete and lung cancer.

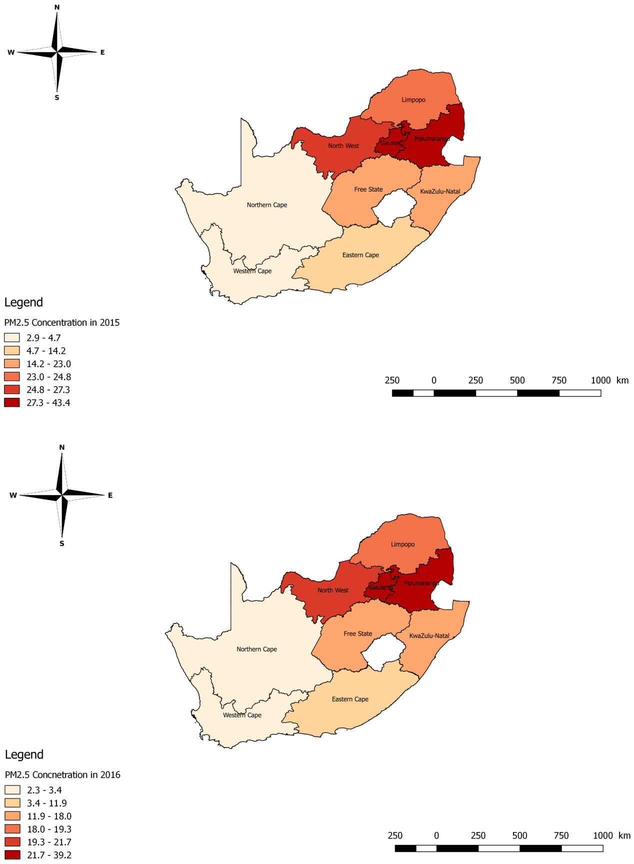

Figure 4.3: Air pollution in 2015 (left) and air pollution in 2016 (right)
Source: Author's own elaboration

In graph 4.3 (graph on the right), we can see a relative clean up of the "Free State" province compared to 2015 (graph 4.3 on the left). This province is very rich in minerals and recognized for its numerous mining activities, especially gold, which represents 20% of world production. Free State also has an industrial sector specialized in high technology. The relative decrease in particulate concentration could probably be explained by a decrease in mining activities or by the use of less polluting technologies.
On the other hand, the "North West" province is less polluted in 2014 (graph 4.2), and has a higher level of pollution during study period. This could be explained by the increase in economic activities which leads to an intensification of road traffic or an increase in industrial or agricultural emissions. Indeed, mining activity is highly developed in this province. There are gold, uranium, diamond and platinum mines. This activity accounts for more than half of the province's GDP and employs one-quarter of the province's labour force. In the same vain, according to NORTH WEST DEVELOPMENT CORPORATION (2023), economy of North West is dominated by Mining industry. The area contributes 23.9% of national mining and 6.9% to national agriculture, but only 2.3% to manufacturing and 3.8% to construction. Air pollution increase would be explained by the rise in mining activities.

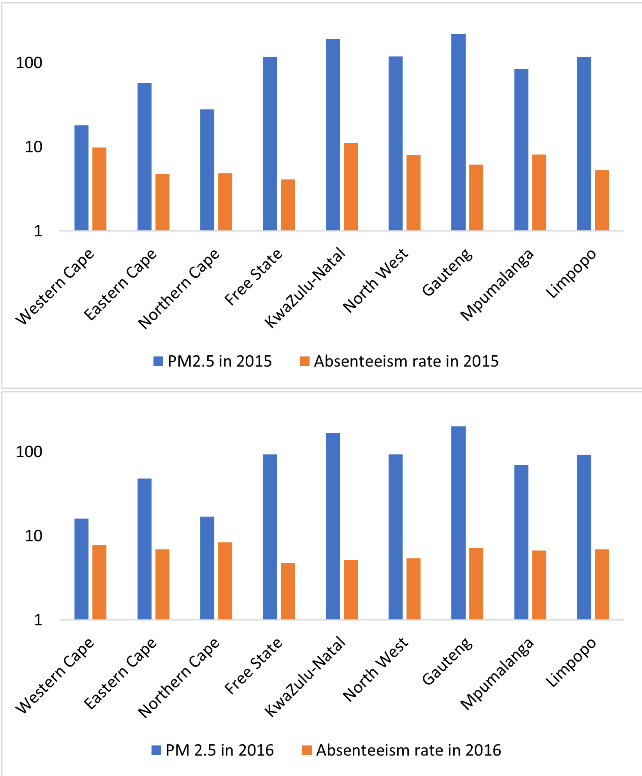

Figure 4.4: Pollution and absenteeism rate by province and year

3.3 Air pollution and absenteeism

Furthermore, the relationship between absenteeism and pollution is not clear. Indeed, through graph 4.4, we can see absenteeism rate can be as high in polluted provinces as in less polluted ones. Therefore, with a simple analysis of the data, we can not find the existence of a clear relationship between pollution and absenteeism. The link between the two phenomena could depend on several aspects that are intrinsic to each province. It could depend, for example, on the level of development and the type of economic activity most practised in the province. In the other words, heterogeneity of each area plays a relevant role in explaining relationship between air pollution and child school absenteeism. To take into account this heterogeneity, province and time fixed effects are used and take into account province- and time-specific effects.

Several previous studies show that pollution affects the economy through human capital (Ostro, 1983; Hausman, 1984; Graff Zivin, 2013). Air pollutants affect the health status of individuals and this leads to a decrease in performance in their activities. There are several reasons why pupils were absent the previous school week. Graph 4.5 shows a small breakdown by reasons for absence. Several reasons explain why pupil did not go to school during previous school week. The most common reason is "illness". Indeed, 555 people were absent because of illness, which is not negligible. In addition, the number of days of absence seems high for some pupils. Indeed, still on Figure 4.5 we can see 42%, 21%, 10%, 5% and 27% have respectively a duration of absence of 1 day, 2 days, 3 days, 4 days and 5 days.

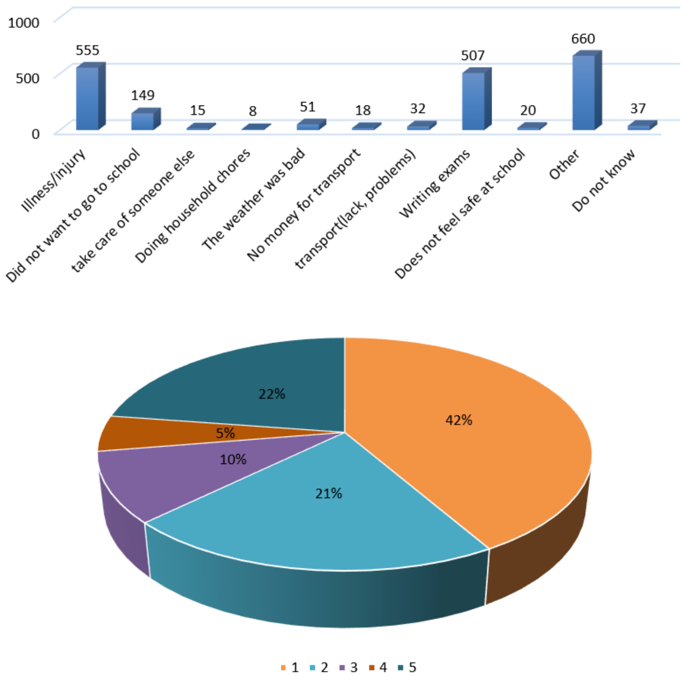

Figure 4.5: Absenteeism reasons (on the left) and duration (on the right)

In Figure 4.6, we see that the average number of days lost during the previous school week differs by province. Information on the number of days absent comes from the question *"For how many days was ... absent during the past school calendar week (Monday to Friday)"*. The number of days lost is high in the provinces of Eastern Cape (in 2016), KwaZulu Natal (in 2015 and 2016), and Gauteng (in 2016). In these areas, students lose an average of 3 school days per year. Furthermore, data analysis shows these provinces also have high PM 2.5 concentration. These lost days negatively influence the school performance of the students and thus on South African human capital.

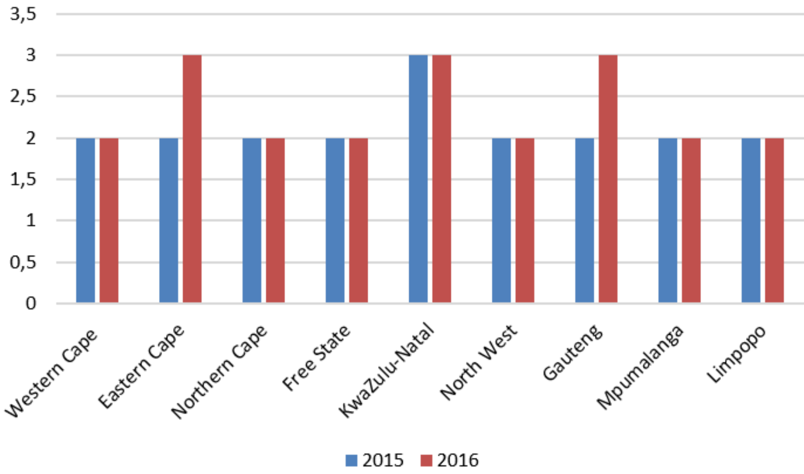

Figure 4.6: Days lost by year and province

After getting an idea of the different reasons for school absenteeism and duration, in Figure 4.7 we relate the level of air pollution (PM2.5 in $\mu g/m^3$) to absenteeism rate due to illness over the period by province. The rate of absenteeism (in %) due to illness is calculated by taking the ratio between the number of absentees due to illness and the total number of absentees. In sum, in the majority of provinces with high concentration of fine particulate matter we can notice that there is a significant rate of absenteeism due to illness. We could imagine the existence of a co-evolution between the number of sick people and pollution level.

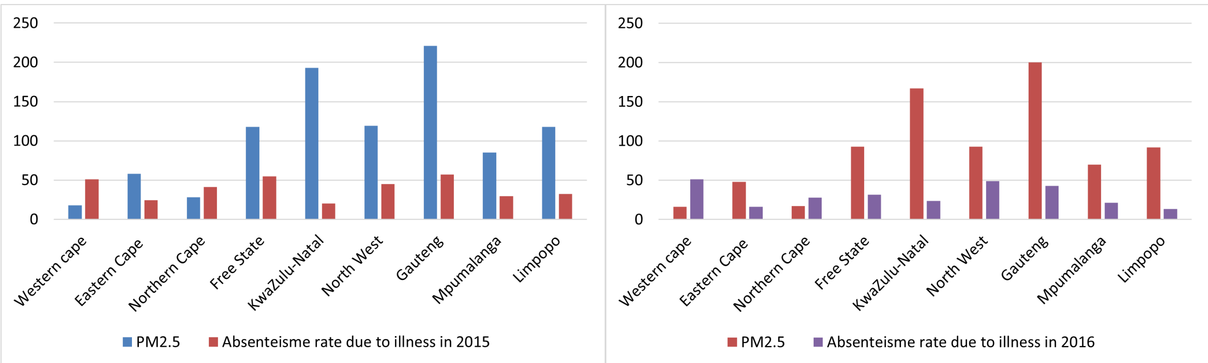

Figure 4.7: PM2.5, absenteeism and illness

3.4 Air pollution, absenteeism and health problems

We decide to understand this relationship by analyzing the relationship between pollution and absenteeism caused by respiratory diseases. In Figure 4.8, we can observe a fairly high rate of absenteeism due to flu or acute respiratory tract infection (ARTI) in some provinces in 2015. This high rate is accompanied in most cases by a fairly high level of pollution. In 2016, there was a decrease in the rate of absenteeism and also a decrease in the rate of absenteeism due to flu or acute respiratory tract infection (ARTI), but it still remains high in some provinces. In view of these figures, we could imagine with some reservations pollution affects school absenteeism through the respiratory diseases it causes. Respiratory diseases could be the transmission channel between pollution and school absenteeism in South Africa. Econometric analysis alone could tell us more about the link between air pollution and school absenteeism in South Africa.

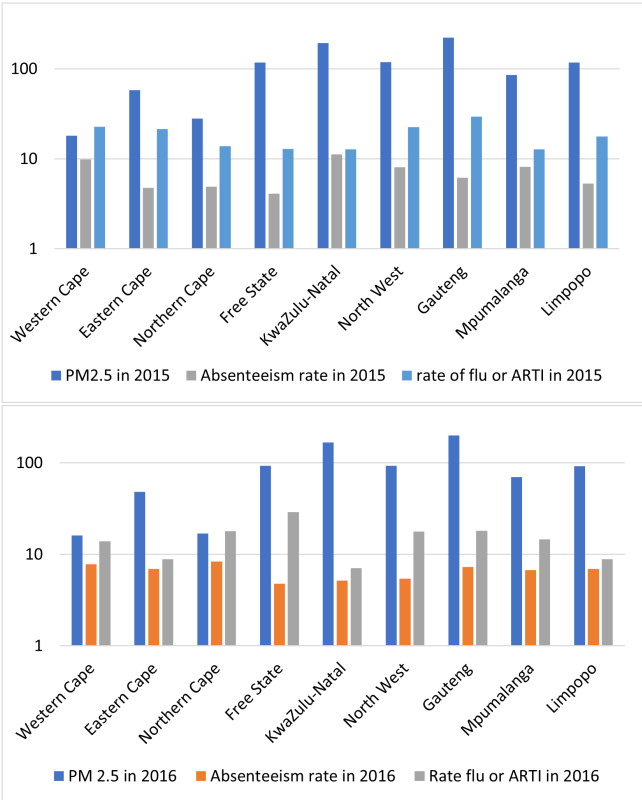

Figure 4.8: Pollution, absenteeism and acute respiratory tract infection

Through the stylized facts highlighted we formulate the following hypotheses which will be tested later:
1) Fine particulate matter pollution affects school absenteeism in South Africa.
2) PM2.5 affects absenteeism through the state of health of individuals.
3) The effect of fine particles on pupil absence is not linear. It depends on provincial and individual characteristics.

4 Econometric analysis

Exposure to air pollution depends on a number of factors which, if not taken into account, could lead to biased economic results. The aim of this section is to address the endogeneity problem and describe the instrumental variable and econometric modeling used.

4.1 Endogeneity issue and instrument choice

This section describes the endogeneity issue and the instruments used.

Endogeneity issue

There are three main sources of endogeneity which are simultaneity bias, omitted variables and measurement error. Air pollution variable is endogenous due to the bias of omitted variables. Our study suffers from the omission of variables that affect the residential choice of individuals. According to Tiebout (1956), individuals choose their residential area on the basis of several factors which may be, among others, the air quality, schools or the quantity of public goods available in the area. Agents choose a place of residence by arbitrating between the different factors. The choice of residence results in a non-random distribution of exposure to PM2.5. Apart from residential choice, other key variables omitted from the study due to data unavailability are road traffic and industrial and mining production by province. Indeed, mining and industrial activity is the main source of particulate matter emissions in South Africa. A second important source is road traffic. Indeed, the use of diesel vehicles favours the emission of particles. For this reason particle sensors detect a high quantity of particles in road tunnels. Certainly, when particles are emitted in tunnels, it remain condensed and take time to dissipate due to lack of ventilation. The use of the instrumental variable method makes it possible to identify and estimate the causal relationship between air pollution and school absenteeism.

Instruments choice

The frequency of particulate matter variation in the atmosphere depends on its concentration and weather conditions such as wind speed and wind direction [1]. Indeed, according to Demirci and Cuhadaroglu (2000) wind is the main transporter of air pollutants. They find a relationship between the air pollution and wind speed. However, the relationship depends on the direction of the wind speed. Wind can carry polluting particles thousands of kilometres away one city to another or from one country to another (Kurita et al., 1985; Cox et al., 1975). It really depends on its speed and direction. Moreover, Lu and Fang (2002); Simpson (1990) successively estimate PM10 and PM2.5 concentrations from wind speed. Lu and Fang (2002) find that difference between the actual pollutant concentrations and those estimated is non-significant at 5%. Wind is a good predictor of pollutant levels. Also, Chaloulakou et al. (2003) find an inverse relationship between PM10 and

[1] U and V components of wind are used to calculate wind direction by applying the formula: $(180/\pi)atan2(v,u)$.

PM2.5 concentrations and wind speed. Furthermore, wind direction as well as wind speed influences PM 2.5 concentration in a given geographical area (Anderson, 2020; Deryugina et al., 2019).

Therefore we use wind speed annual average (measured in m/s) and wind direction annual average (measured in degrees) at provincial level as instruments. The raw data come from the the European Centre for Medium-Range Weather Forecasts (ECMWF) database and have a resolution of 0.5° (about 50km). Figure 4.9 shows a negative correlation between pollution level and wind speed. A low wind speed results in a high pollution level in the province. In Figure 4.10 we can see wind direction is also correlated to the pollution level of the considered area. These two graphs are consistent with the results of Lu and Fang (2002), Simpson (1990) and Chaloulakou et al. (2003).

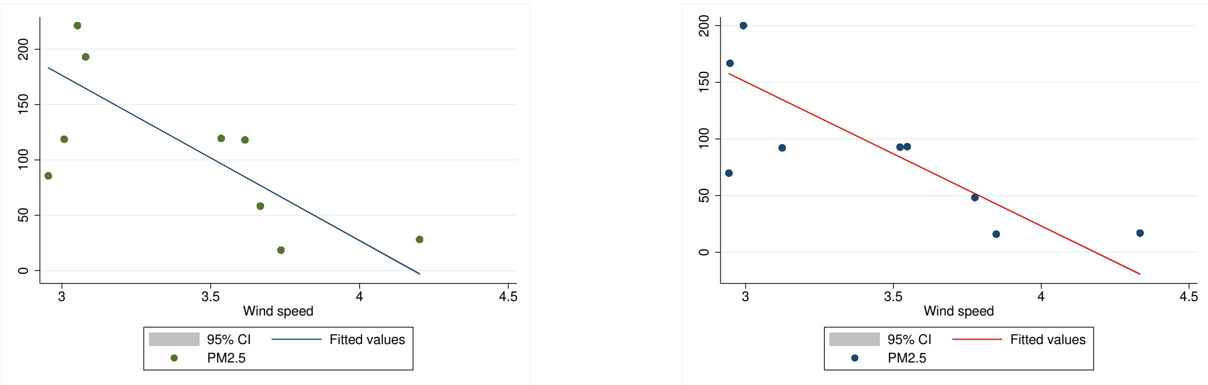

Figure 4.9: Relation between PM2.5 and wind speed in 2015 (left) and 2016 (right)

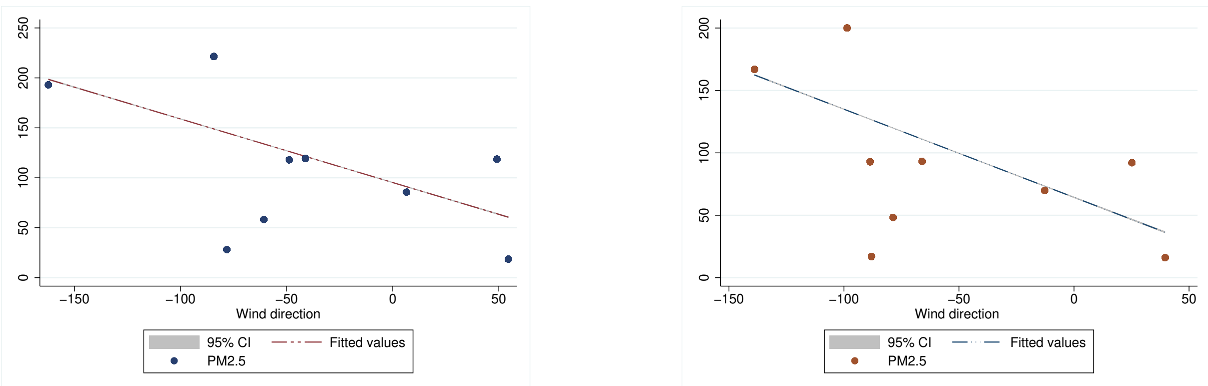

Figure 4.10: Relation between PM2.5 and wind direction in 2015(left) and 2016 (right)

Also, as additional instrument we add temperature inversion episodes which is a phenomenon that implies an increase in temperature with altitude while the theory indicates the opposite. Jans et al. (2018) and Arceo et al. (2016) show temperature inversions affect pollutant concentration because it leads to its concentration in the atmosphere. There is a relationship between the number of temperature inversion episodes and the level of pollutants and Figure 4.11 shows this correlation between the two phenomena. We can see on average the areas with a high level of pollution (PM2.5 in $\mu g/m^3$) also observe a high number of temperature inversion episodes.

To get data on temperature inversion events we use satellite data and pixels of about 25km square. For each pixel, we make the difference between the daily temperature at 1000 hpa and the temperature at 925 hpa [2] (Jans et al., 2018). We then calculate for each province the number of pixels where the result is negative, i.e. where there has been a temperature inversion. We then obtain the number of temperature inversion episodes per province for each year. This is more accurate than calculating the temperature difference over the entire province, as a small area of inversion is likely to be compensated for by areas without inversion.

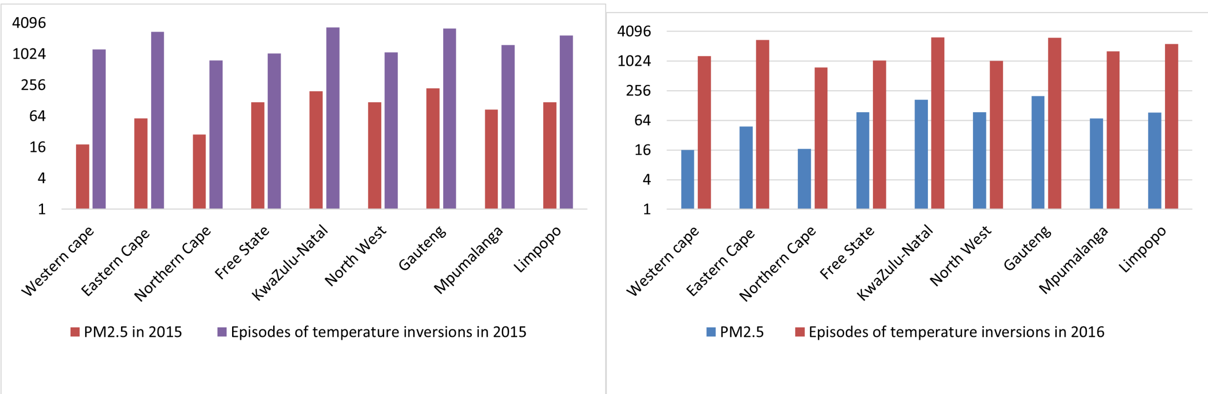

Figure 4.11: Relation between PM2.5 and temperature inversions

In addition, good quality instruments comply with the conditions of rank and exclusion. Wind speed, wind direction and temperature inversions affect PM 2.5 concentration in the atmosphere (Chaloulakou et al., 2003; Lu and Fang, 2002; Simpson, 1990; Jans et al., 2018; Arceo et al., 2016). The rank condition is therefore met. Moreover, these instruments do not have a direct impact on the school absence of pupils. Although it should have an effect on school absenteeism, the effect is conveyed by the quantity of pollutants in the atmosphere as a result of wind and temperature inversions. The exclusion condition is verified.

[2] Temperature at 1000 hpa corresponds to the surface conditions and temperature at 925 hpa corresponds to the conditions at approximately 600 m above sea level

4.2 Control Function Method

Control function (CF hereafter) approach of Wooldridge (2015) is similar to two stage least squares (2SLS) approach. But, it has some interesting advantages over 2SLS. First, the CF estimator allows the comparison of OLS and 2SLS through a Hausman (1978) test, is robust to heteroscedasticity, cluster and serial autocorrelation. The second advantage is CF method allows to treat carefully nonlinear models with endogenous variables.
Indeed, there are very few methods that deal with endogeneity problems in the case of nonlinear panel models. We identify two methods that could be applied to our case: CF method and the generalized structural equation model (Drukker, 2014). But the CF method is the most intuitive because it is close to 2SLS. Details on CF method framework can be found in Part A of the Appendix.

Application

In this study we use a dichotomous model which is a model where the explained variable has two (02) modalities (0 and 1). The modality is 1 if pupil was absent during the last school week at school and 0 otherwise. We can choose between two types of dichotomous models: probit model and logit model. We use a logit model because it has advantages in the interpretation of marginal effects. CF method of Wooldridge (2015) is applied in the following two steps:

- First stage equation: Application of fixed effect model because there are heterogeneous specific effects that have to be taken into account and also because result of the Hausman test is favorable for the fixed effects model.

  $PM_{pt} = \gamma Z_{1pt} + \theta Z_{2pt} + \lambda X_{ipt} + V_{pt}$ (2)

Where Z_{1pt} and Z_{2pt} are the instruments. PM_{pt}, X_{ipt} and V_{pt} represent respectively pollution, control variables and residuals.

- Second stage equation: Application of logit model with random effects

  $P(Y_{ipt} = 1) = \phi(\alpha + \beta PM_{pt} + \lambda X_{ipt} + \mu \hat{V_{pt}})$ (3)

Where X_{ipt} and $\hat{V_{pt}}$ are respectively control variables and estimated residuals.

4.3 Results

The main results are in table 4.1 and in all tables we present the marginal effects. Pollution has a positive effect on the probability of children's absence from school. An increase in PM2.5 concentration by 10 $\mu g/m^3$ results in a 1.33 to 2.46 percent risk of absenteeism. This result is consistent with previous studies (Ransom and Pope III, 1992;

Makino, 2000; Park et al., 2002; Ransom and Pope, 2013; MacNaughton et al., 2017) and could be explained by the health problems induced by air pollution. According to Umwelthilfe (2019), children are the most exposed to pollution due to their size because pollutants are 37 times more concentrated at one metre above the ground than at two metres. This implies children inhale more pollutants than adults. Their exposure to pollution has major repercussions such as respiratory and infectious diseases, asthma and delayed development of the respiratory system and lungs that can lead to a long-term risk of developing respiratory diseases. Exposure of pupils to pollution is increased by the geographical location of schools. In Africa majority of primary schools are located close to major roads. Road traffic is one of the main sources of PM2.5 emissions in addition to the agricultural and industrial sector. As a result, children could breathe poor air quality in schools or on the road to school.

Moreover, travel time between home and school has a positive effect on the probability of children being absent from school. The greater the distance, the greater the risk of absenteeism. A school that is too far from home could demotivate the child's attendance due to the constraints it imposes. Indeed, child may not always want to spend a lot of time getting to school or the parents may not be available to accompany their child to school every time due to time constraints for example. Moreover, travel time also contributes to the exposure of children to pollution. A long commuting time to school results in a high exposure to air pollution due to the time it takes in road traffic to get to school.

In addition, results show the lack of teachers has a positive and significant effect on child's absence from school, which is logical. Teachers who are supposed to transmit knowledge are the reason for the presence of children at school. If they are absent, there is no reason why the children should not be. Lack of teachers has a positive marginal effect of about 44% on the probability of children's absence. Therefore this issue affects pupil's school attendance in South Africa. This result is similar to that found by Case and Deaton (1999); Visser et al. (2015).

Furthermore, results show child's age has effect on school attendance. A one-year increase in age reduces the risk of absenteeism by 0.18%. Indeed, age level could actually determine the child's schooling level. The closer the child is to an exam class or is even in an exam class, some parents give more importance to the child's schooling and thus ensure his or her school attendance.

Table 4.1: Baseline Results

	Absence	Absence	Absence	Absence	Absence
PM2.5	0.00246***	0.00242***	0.00151**	0.00133*	0.00195*
	(3.64)	(3.46)	(2.08)	(1.87)	(1.73)
Child's gender(Female=1)		-0.00190	-0.00420	-0.00413	-0.00405
		(-0.50)	(-0.97)	(-0.94)	(-0.92)
Child's age		-0.000867	-0.00133*	-0.00177**	-0.00177**
		(-1.41)	(-1.88)	(-2.38)	(-2.39)
Head gender(Female=1)		0.00389	0.00360	0.00272	0.00281
		(0.77)	(0.50)	(0.37)	(0.38)
Head education		-0.00175***	-0.00129*	-0.00121	-0.00124
		(-3.12)	(-1.73)	(-1.57)	(-1.60)
Wealth index			0.00163	0.00134	0.00132
			(0.46)	(0.37)	(0.36)
Household size			0.00102	0.00130	0.00130
			(0.84)	(1.04)	(1.04)
Biological father presence			0.00293	0.00299	0.00272
			(0.39)	(0.39)	(0.35)
Biological mother presence			0.00853	0.00912	0.00936
			(1.42)	(1.49)	(1.53)
Lack of teacher				0.0378*	0.0374*
				(1.87)	(1.85)
Time to travel to school				0.0141**	0.0140**
				(2.45)	(2.43)
Relative humidity					0.00450**
					(2.17)
Rainfall					0.000138
					(1.29)
Province FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Observations	19225	17535	13428	13008	13008
Cluster variable	hh	hh	hh	hh	hh
LR test P value		0.0000	0.0000	0.0000	0.0247
Converged	yes	yes	yes	yes	yes
R^2	0.006	0.10	0.32	0.33	0.34

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The table shows marginal effects

The explained variable "Absence" is 1 if the child was absent during the previous school week and 0 otherwise

In addition, the household head education level negatively influences the risk of the child's absence from school. The fact that household head has a high level of education enables child to give more importance to school for success in life or to have a source of income in the future. Thus, the higher the level of education of the household head, the more importance he or she attaches to the educational success of the child.

Moreover, meteorological conditions more precisely relative humidity affects absenteeism. It impacts through the diseases that bad weather conditions could cause (Currie et al., 2009; Lepeule et al., 2018).

5 Health transmission channels

Earlier literature links school absenteeism due to pollution to the health problems it causes (Romieu et al., 1992; Gilliland et al., 2001). Pollution affects the education of pupils through the cardio-pulmonary problems it creates. As a result, children's attendance would depend of severity of the disease. Those who are less ill could be present but less receptive to the knowledge which are taught in class. On the other hand, those who are seriously ill would not be able to attend and would risk missing several days of classes.

To test the "health" channel revealed by previous studies (Kampa and Castanas, 2008; Pope III and Dockery, 2006), some "health" variables whose results are used and presented in Table 4.2. The "health" variables tested obtained from the questions *"During the past three months, did... suffer: 1=Flu or acute respiratory tract infection, 2=diarrhoea, 3= Severe cough with blood, 4=abuse of alcohol or drugs, 5=depression, 6= sexual transmitted diseases, 7=pneumonia, 8=bronchitis, 9=epilepsy"* and *"Did... consult a health worker such as a nurse, doctor or traditional healer as a result of this illness?*

To test the transmission channels, we use stepwise regression by reference to the study of Zhou et al. (2022). This method allows us to determine the mediation effects through the following equations:

$$Absence = \alpha PM2.5 + \epsilon_1 \ (1)$$
$$M = \beta PM2.5 + \epsilon_2 \ (2)$$
$$Absence = \theta PM2.5 + \rho M + \epsilon \ (3)$$

Where M is the mediation variable. The last step of the applied method differs from that of Zhou et al. (2022) because we have taken into account the control variables in equation (3). This allows us to capture the mediation effect of the transmission channels in the baseline model. A logit model is used for testing because the dependent variable and transmission channels are binary.

Results show "medical consultation" and "Flu or acute respiratory tract infection (ARTI)" are transmission channels. In table 4.2, we can see air pollution affects the transmission channels (columns 2 and 6) and these transmission channels also affect absenteeism (columns 3 and 7). It can be said that pollution acts on school absenteeism through "medical consultation" and "flu or ARTI". And it is important to note that this is a partial intermediary effect as the effect of pollution is still significant when transmission channels are added to the baseline model (He et al., 2022).

Results show pollution partially affects child school attendance through the diseases and more precisely respiratory diseases. Indeed, exposure to pollution causes respiratory diseases that can prevent pupils from attending school. This could have a negative effect on their school performance.

In the next section, we test the robustness of the baseline results by changing the model and the estimator.

Table 4.2: Transmission channel

	Medical consultation	Absence	Cough	Absence	Flu or ARTI	Absence
PM2.5	0.000108***	0.00197*	0.00000859*	0.00195*	0.0000980**	0.00192*
	(2.65)	(1.75)	(1.77)	(1.73)	(2.07)	(1.72)
Medical consultation		0.0593***				
		(7.31)				
Cough				0.0289		
				(0.46)		
Flu or ARTI						0.0618***
						(8.90)
Child's gender(Female)		-0.00372		-0.00403		-0.00310
		(-0.85)		(-0.91)		(-0.71)
Child's age		-0.00131*		-0.00178**		-0.00121
		(-1.77)		(-2.40)		(-1.64)
Head gender(Female)		0.00240		0.00284		0.00231
		(0.33)		(0.39)		(0.32)
Head education		-0.00134*		-0.00124		-0.00139*
		(-1.74)		(-1.60)		(-1.80)
Wealth index		0.00277		0.00135		0.00290
		(0.76)		(0.37)		(0.80)
Household size		0.00162		0.00130		0.00181
		(1.32)		(1.04)		(1.47)
Biological father presence		0.00321		0.00271		0.00377
		(0.42)		(0.35)		(0.49)
Biological mother presence		0.00935		0.00936		0.00862
		(1.52)		(1.53)		(1.40)
Lack of teacher		0.0312		0.0375*		0.0296
		(1.62)		(1.85)		(1.59)
Time to travel to school		0.0138**		0.0140**		0.0133**
		(2.39)		(2.44)		(2.32)
Relative humidity		0.00439**		0.00450**		0.00443**
		(2.12)		(2.17)		(2.14)
Rainfall		0.000136		0.000138		0.000138
		(1.27)		(1.29)		(1.29)
Province FE	No	Yes	No	Yes	No	Yes
Time FE	No	Yes	No	Yes	No	Yes
Observations	13008	13008	13008	13008	13008	13008

t statistics in parentheses

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

6 Robustness checks

The results remain unchanged following the use of Generalized Structural Equation Modeling which is an alternative method to CF to fix endogeneity problem (Drukker, 2014) and probit model with random effects. We can see pollution always has a positive effect on the probability of school absence (Table 4.3).

Table 4.3: Robustness with probit modeling and GSEM

	Probit	GSEM
PM 2.5	0.00192*	0.0322**
	(1.70)	(2.01)
Child's gender(Female=1)	-0.00410	-0.0663
	(-0.93)	(-0.87)
Child's age	-0.00173**	-0.0315**
	(-2.35)	(-2.44)
Head gender (Female=1)	0.00284	0.0538
	(0.39)	(0.43)
Head education	-0.00123	-0.0207
	(-1.59)	(-1.55)
Wealth index	0.00124	0.0277
	(0.34)	(0.44)
Household size	0.00134	0.0216
	(1.07)	(1.02)
Biological father presence	0.00249	0.0453
	(0.33)	(0.35)
Biological mother presence	0.00947	0.166
	(1.55)	(1.47)
Lack of teacher	0.0375*	0.520**
	(1.87)	(2.21)
Time to travel to school	0.0141**	0.247**
	(2.46)	(2.45)
Relative humidity	0.00446**	0.0772**
	(2.18)	(2.15)
Rainfall	0.000139	0.00222
	(1.30)	(1.31)
Province FE	yes	yes
Time FE	yes	yes
Wind speed		-127.0***
		(-95.88)
Wind direction		-0.319***
		(-48.04)
Temperature inversions		-0.00536***
		(-24.91)
Observations	13008	15526
Cluster variable	hh	hh
Converged	yes	yes

t statistics in parentheses

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

7 Heterogeneity of effect

In the following lines, I test the non-linearity of the impact as a function of the characteristics of the individual, household head and the household.

7.1 Effect by age and socio-Economic Status

Income level allows household to protect itself against the effects of air pollution. Indeed, we know that according to the concept of "voting with their feet" of Tiebout (1956), individuals can move if the living conditions of their current geographical area are not convenient for them. Thus, when there is a deterioration of air quality, wealthy households prefer to move to an area with less air pollution. The geographical distribution of individuals would be such that wealthy households will tend to move to less polluted areas compared to poor households who do not have enough financial means to move to residential areas.

The results obtained are not in line with the concept of "voting with their feet" of Tiebout (1956). Indeed, in table 4.4 (column 3 and 4), we can see pollution has not an impact on the school absenteeism of children from poorest households. According to Hajat et al. (2013); Neidell (2004); Pratt et al. (2015) wealthier households have more opportunity to protect themselves from air pollution because of "avoidance behavior". Indeed, they can change their place of residence by choosing a less polluted area and can also protect themselves by buying protective equipment such as masks. Poor households, however, do not have all these opportunities. The result we get could be explained by the failure to take environmental factors into account in the household's choice of residence. Indeed, according to Lesia et al. (2023) the choice of residence of South African households is influenced by demographic characteristics, dwelling unit features, neighbourhood features, services provided by the government, household self-congruity, functional congruity, green building features and stakeholders' relations.

Furthermore, individual's age could lead to heterogeneity in the effect of pollution. Results in Table 4.4 show that individuals aged 16 years or more are more impacted compared to the younger ones and more specifically, individuals of study sample. This could be explained by the fact that older individuals are more likely to be outside the house.

Table 4.4: Effect by individual's age and household wealth

	age < 16	age >= 16	25% poorest	25% wealthiest
PM 2.5	0.00195*	0.00434**	0.00308	0.00463**
	(1.73)	(2.39)	(1.24)	(2.22)
Child's gender(Female=1)	-0.00405	-0.00884	-0.0262***	0.0147
	(-0.92)	(-0.95)	(-2.94)	(1.64)
Child's age	-0.00177**	0.00441**	-0.000728	-0.00424**
	(-2.39)	(2.51)	(-0.52)	(-2.55)
Head gender (Female=1)	0.00281	0.00990	-0.00356	0.0164
	(0.38)	(0.69)	(-0.28)	(1.06)
Head education	-0.00124	0.00129	-0.00264*	-0.00145
	(-1.60)	(1.02)	(-1.84)	(-0.97)
Wealth index	0.00132	0.00590		
	(0.36)	(0.92)		
Household size	0.00130	0.0000983	-0.00344	0.00155
	(1.04)	(0.05)	(-1.30)	(0.64)
Biological father presence	0.00272	0.000405	0.00314	0.000987
	(0.35)	(0.03)	(0.25)	(0.06)
Biological mother presence	0.00936	0.0212**	0.00273	-0.00462
	(1.53)	(1.98)	(0.18)	(-0.38)
Lack of teacher	0.0374*	0.0118	-0.0188	0.0308
	(1.85)	(0.39)	(-0.68)	(0.71)
Time to travel to school	0.0140**	0.0151	0.0123	0.0166
	(2.43)	(1.31)	(1.11)	(1.30)
Relative humidity	0.00450**	0.0110***	0.000732	0.00403
	(2.17)	(2.84)	(0.17)	(0.73)
Rainfall	0.000138	0.000513***	0.000316	0.000369*
	(1.29)	(2.79)	(1.28)	(1.79)
Province FE	yes	yes	yes	yes
Time FE	yes	yes	yes	yes
Observations	13008	3569	3173	3093
Cluster variable	hh	hh	hh	hh
Converged	yes	yes	yes	yes

t statistics in parentheses

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

7.2 Effect by subgroup

South Africa has a diverse population, which leads to cultural diversity that may affect the lifestyles of individual households. The objective of this section is to see if there is heterogeneity in the effect depending on the cultural subgroup of the household head. Specifically, to see if the effect varies depending on whether the head of the household is black or not. According to Heissel et al. (2019), in Florida the effect of pollution affects the academic performance of black pupils while the effect is null on the performance of other pupils. Our goal is to see if there is a difference in the effect in South Africa.

Table 4.5: Effect by household head subgroup

	Black	Coloured
PM2.5	0.00241*	-0.0300**
	(1.91)	(-2.37)
Child's gender(Female=1)	-0.00234	-0.0194
	(-0.51)	(-1.19)
Child's age	-0.00181**	-0.00272
	(-2.30)	(-0.99)
Head gender(Female=1)	0.00373	-0.00668
	(0.47)	(-0.30)
Head education	-0.000979	-0.00490*
	(-1.23)	(-1.65)
Wealth index	0.000298	0.0138
	(0.07)	(1.07)
Household size	0.00210	-0.00717*
	(1.62)	(-1.66)
Biological father presence	0.00264	-0.0125
	(0.31)	(-0.55)
Biological mother presence	0.00638	0.0340
	(1.00)	(1.51)
Lack of teacher	0.0360	0.0190
	(1.60)	(0.44)
Time to travel to school	0.0155**	0.00767
	(2.51)	(0.41)
Relative humidity	0.00450*	-0.0190
	(1.81)	(-1.38)
Rainfall	0.000181*	-0.00177**
	(1.75)	(-2.06)
Province FE	Yes	Yes
Time FE	Yes	Yes
Observations	11303	1248
Cluster variable	HH	HH
converged	Yes	Yes

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In the sample, household heads were divided into 4 subgroups (black African, Coloured, Indian or Asian and white). Only 2 groups (black and coloured) are used because of the convergence problems encountered with the other groups. For exemple, the Indian/Asian and White groups were grouped together but there was still a problem of convergence. In a logistic model, lack of convergence is due to the fact that the likelihood maximization algorithm does not converge. Table 4.5 shows very interesting results according to the group to which the household head belongs. In households with a black head, the marginal effect of pollution on the risk of absenteeism is positive, but it is negative in households with a coloured head.

This result could be explained by the socio-economic status of households with a coloured head. Indeed, a high level of pollution could approximate the level of economic activity. For these households, more pollution could mean more income. Head of the household could therefore invest better and be involved in the education of the children. This could result in a lower level of absenteeism.

7.3 Effect by household size and composition

Households may differ in size or composition and this could influence individual's behavior in the household. It is relevant to take this into account as it could lead to heterogeneity in the effect of air pollution on school attendance. Therefore, we first investigate the difference in the effect according to the size of the household (Table 4.6). Studies show that household size influences education and well-being of children (Dang and Rogers, 2016; Cáceres-Delpiano, 2006; Ponczek and Souza, 2012). Parents make a trade-off between quantity and quality of children. Instead of having many children, they focus on the quality of children by investing in their education and well-being. In this vein Dang and Rogers (2016) shows Vietnamese parents will tend to invest less in the schooling of a child with several siblings. One could imagine the size of the South African household would influence parental investment in the quality of children.

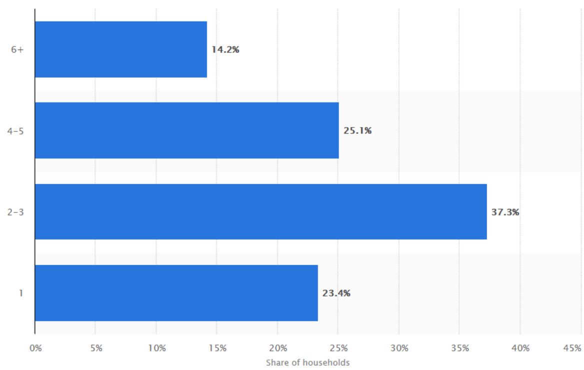

Figure 4.12: Distribution of households in South Africa in 2019, by household size
Source: Statista 2021

Results are shown in Table 4.6. We can see the fact that household is formed of at least 6 members positively affects air pollution impact on truancy. Therefore, the effect of air pollution on the risk of absenteeism in South Africa depends on the size of the household. We use the distribution of South African households by size in 2019 (Statista 2021) to study this heterogeneity. Figure 4.12 shows a distribution of households into four size classes. We can see that 37.3% of the households were formed by 2 or 3 individuals. We are interested only in households with a size greater than or equal to 2 because a household of one individual means there are no children. Whereas a two-member household can be formed by one of the parents and the child.

Table 4.6: Effect by household size

	Size=2 or 3	Size= 4 or 5	Size >= 6
PM2.5	0.00179	0.0000839	0.00395**
	(0.73)	(0.05)	(2.57)
Child's gender(Female=1)	0.00125	-0.0105	-0.00406
	(0.12)	(-1.62)	(-0.66)
Child's age	0.0000695	0.000170	0.0000784
	(0.05)	(0.20)	(0.09)
Head gender(Female=1)	0.00939	-0.00207	0.00461
	(0.51)	(-0.17)	(0.44)
Head education	-0.00105	-0.00111	-0.000824
	(-0.62)	(-1.04)	(-0.73)
Wealth index	0.00176	0.00733	-0.00295
	(0.25)	(1.57)	(-0.45)
Biological father presence	-0.00144	0.00451	0.00169
	(-0.07)	(0.36)	(0.16)
Biological mother presence	0.0155	0.0110	0.0144*
	(1.17)	(1.13)	(1.71)
Lack of teacher	0.00766	0.0576*	0.00845
	(0.23)	(1.88)	(0.32)
Time to travel to school	0.0129	0.00861	0.0192**
	(1.08)	(1.10)	(2.09)
Relative humidity	0.0101**	0.00584**	0.00284
	(2.36)	(2.09)	(0.76)
Rainfall	0.0000622	-0.0000340	0.000327**
	(0.26)	(-0.20)	(2.17)
Province FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Observations	2115	5629	7450
Cluster variable	hh	hh	hh
Converged	Yes	Yes	Yes
R^2	0.43	0.36	0.35

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Moreover, composition of the household could affect pollution's effect. Indeed, among the determinants of school absenteeism, presence of biological parents in the household plays an important role. Case and Ardington (2006) shows that whether parents are alive or not has a different effect on children's school performance. In order to take this aspect into account, we analyze the effect of air pollution on school attendance according to the presence of biological parents in the household. The results show that the marginal effect of pollution is zero when the biological mother is present in the household, and the effect becomes positive when the biological mother does not live in the household (Table 4.7 columns 1 and 2). The effect of pollution on the risk of absenteeism is zero, regardless of whether the biological father is present or not (Table 4.7 columns 3 and 4). On the other hand, the marginal effect is positive when none of the biological parents is present in the household (column 4). Moreover, the marginal effect is zero when the biological mother is present and the biological father is absent, or when both biological parents are present in the household. These results show the importance of the biological mother's presence on the child's school attendance. This is because the biological mother takes care of the child when she is present. She looks after the child's health and well-being.

Table 4.7: Effect by household structure

	Bio mother in the HH	Bio mother no in the HH	Bio father in the HH	Bio father no in the HH	Bio father no in the HH & bio mother no in the HH	Bio father no in the HH & Bio mother in the HH	Bio father in the HH & Bio mother no in the HH	Bio father in the HH & Bio mother in the HH
PM2.5	0.00130	0.00345*	0.00184	0.00197	0.00342*	0.00102	0.00273	0.00201
	(0.99)	(1.83)	(1.03)	(1.47)	(1.75)	(0.61)	(0.39)	(1.03)
Child's gender(Female)	-0.00625	0.00183	-0.00967	-0.000651	0.00134	-0.00191	0.0298	-0.0111
	(-1.22)	(0.23)	(-1.34)	(-0.12)	(0.16)	(-0.27)	(0.68)	(-1.50)
Child's age	-0.00174**	-0.00174	-0.00178	-0.00179*	-0.000630	-0.00242**	-0.0199***	-0.000914
	(-2.05)	(-1.17)	(-1.49)	(-1.88)	(-0.41)	(-2.03)	(-2.97)	(-0.76)
Head gender(Female)	0.00135	0.0127	-0.00514	0.00282	0.00915	0.00260	0.0586	-0.0154
	(0.20)	(1.24)	(-0.33)	(0.35)	(0.85)	(0.23)	(1.31)	(-0.77)
Head education	-0.00119	-0.00135	-0.000236	-0.00135	-0.00127	-0.00190*	-0.00694	0.000216
	(-1.29)	(-1.06)	(-0.16)	(-1.64)	(-0.93)	(-1.82)	(-0.88)	(0.13)
Wealth index	0.000863	0.00280	0.00482	-0.00109	0.00927	-0.00702	-0.0535*	0.00836
	(0.21)	(0.37)	(0.92)	(-0.21)	(1.26)	(-1.07)	(-1.68)	(1.57)
Household size	0.000994	0.00156	0.00238	0.000774	0.00106	0.000395	0.00519	0.000957
	(0.70)	(0.81)	(1.02)	(0.58)	(0.52)	(0.25)	(0.57)	(0.36)
Lack of teacher	0.0265	0.0827	0.00930	0.0541*	0.0746	0.0411	0.108	0.00372
	(1.33)	(1.56)	(0.38)	(1.90)	(1.37)	(1.42)	(0.87)	(0.15)
Time to travel to school	0.0176***	0.00393	0.0152	0.0138**	-0.00120	0.0225**	0.108*	0.0124
	(2.66)	(0.38)	(1.64)	(1.98)	(-0.12)	(2.55)	(1.80)	(1.30)
Relative humidity	0.00383	0.00553	0.00653*	0.00377	0.00512	0.00215	0.0103	0.00644*
	(1.62)	(1.17)	(1.80)	(1.43)	(1.03)	(0.67)	(0.34)	(1.76)
Rainfall	0.000111	0.000169	0.0000526	0.000163	0.000177	0.000133	-0.0000945	0.0000660
	(0.88)	(0.96)	(0.28)	(1.27)	(1.00)	(0.82)	(-0.11)	(0.33)
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9637	3371	4820	8188	3033	5118	199	4519

t statistics in parentheses

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

8 Conclusion

This study focuses on the impact of pollution on human capital. It looks at absenteeism among children aged 5 to 15 years in South Africa in 2015 and 2016. The choice of age group is based on the country's education system, where primary school pupils are between 5 and 15. Results show pollution has a significant positive effect on the risk of child school absence. The marginal effect is between 1.33 and 2.46% following a 10 $\mu g/m^3$ increase in the average concentration of PM 2.5. In this way, the study contributes to the literature by removing ambiguity about the effect of air pollution on school absenteeism. Other factors such as child's age, education level of the household head, lack of teacher, travel time between home and school, annual relative humidity also affect school absenteeism. Moreover, the impact varies by individual and household characteristics.

Moreover, data analysis and previous literature (Romieu et al., 1992; Gilliland et al., 2001; Kampa and Castanas, 2008; Pope III and Dockery, 2006) show the effect of pollution on school absence is explained in particular by the health problems it induces. Pollution would therefore affect children's schooling via the "health" channel. Also, the results obtained are in line with those found by some of the previous studies (Ransom and Pope III, 1992; Makino, 2000; Park et al., 2002; Ransom and Pope, 2013; MacNaughton et al., 2017) (Table A1).

Furthermore, in terms of environmental policies, the country is lagging somewhat behind, as are most developing countries. The South African authorities first became interested in particulate matter in 2012. Under the Air Quality Act of 2004, they are adding standards for PM2.5 concentration. The country sets as standards an annual PM2.5 concentration level of 25 $\mu g/m^3$ between 2012 and 2015, then a concentration of 20 $\mu g/m^3$ between January 2016 and December 2029 and finally a concentration of 15 $\mu g/m^3$ from January 2030. To protect population from the harmful effects of air pollution, South African leaders must ensure measures are respected. Also they must play an active role to fight global warming. Indeed, global warming is the main reason for the concentration of particles in the atmosphere because it leads to wide fluctuations in rainfall and even absence of rainfall in some regions. Rain cleans the air of the particulate matter and pollutants it contains. As a result, the less rain there is, the more particulate matter there are in the atmosphere that negatively affect the health of individuals. Another important recommendation is the relocation or construction of schools away from high road traffic areas.

An important limitation of this study is the time dimension of "health" variables which serve as transmission channels. As for question asked in the questionnaire, the variables concerned identify individuals who have fallen ill in the last three months, whereas the question on absenteeism concerns child who have been absent during the previous school week. There is therefore a problem with the time dimension. It is possible pupils who have been ill in the last three months may have been present during the previous school week. This could lead to an underestimation of the effect of pollution passing through the transmission channel. Another limitation lies in the geographical precision of the households. Indeed, data are not geo-referenced. Therefore we do not have a precise idea of the location of households. The province of residence of households is the only information we have. Information on the city of residence, for example, would allow us to have more precise information on the level of pollution to which households are exposed. Also, it is implicitly assumed that the observed level of absenteeism corresponds to the annual absenteeism level of the province. The lack of air pollution data over the survey period leads us to make this implicit assumption.

Future research could attempt to address the various limitations of this paper, particularly with regard to information on household location. Another research idea would be to try to understand why the effect of air pollution differs according to the population subgroups to which the household head belongs.

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Appendices

A Literature review : Air pollution and school absenteeism

Studies	Statistical / Econometric setup	Interest Variable	Dependent variable	Sample	Key findings
Wayne and Wehrle (1969)	Correlation Study	KI (potassium iodide)	Absence rates attributed to respiratory illness	Two elementary schools in Los Angeles Sept 17, 1962, to June 21, 1963 Country: USA	No significant effect of KI on school absenteeism
Ransom and Pope III (1992)	lagged moving average models Various unrestricted and polynomial distributed lag models	PM10 in µ/m3	Weekly and daily attendance	Valley located in Utah County 6 school districts Period of study: 1985-1990 Country: USA	Positive impact of PM10 on elementary school absences
Romieu et al. (1992)	Logistic regression mode	O3 (ozone)	respiratory related school absenteeism	The southwestern part of Mexico City 111 preschool children Country: Mexico	Positive impact of O3 on respiratory-related school absenteeism
Makino (2000)	Logistic regression Poisson regression Quintile method Correlation analyse	Suspended particulate matter (SPM) Nitrogen dioxide	Daily absence	Between 534-648 schoolchildren, Two school around arterial roads Period: 1993 to 1997 Country: Japan	Positive effect of SPM and nitrogen dioxide on school absence
Chen et al. (2000)	Time-series autoregression Analysis	PM10 CO O3	Daily elementary school absenteeism	57 elementary school of washoe county 27793 student Period: 1996 to 1998 Country: USA	Negative effect of PM10 Positive effect of CO and O3 on elementary school absenteeism
Gilliland et al. (2001)	Poisson log-linear model	PM10 O3 NO2 (nitrogen dioxide)	Daily absence	2081 children of 4th grade school Children of 12 southern California communities Period: first 6 months of 1996 Country: USA	Positive effect of O3 on respiratory illness-related absence rates No significant effect of PM10 and NO2
Park et al. (2002)	Generalized additive poisson regression	PM10 O3 NO2 SO2	Daily illness-related absence	One elementary shool of Seoul, March 2, 1996 to december 22, 1999	Positive effect of PM10, 03 and SO2 No significant effect of NO2
Rondeau et al. (2005)	Logistic transition model with random effects	PM10 O3	Daily absence	12 Southern California communities 1932 children aged 9-10 years	No significant effect of PM10 No clear effect of O3
Currie et al. (2009)	Difference-in-difference-in-differences strategy	CO (carbon monoxide)	Aggregated six-week attendance period	The 39 largest school dscrict of texas Period: 1996 to 2001 Country: USA	Positive effect of CO in elementary and middle school absence
Ransom and Pope (2013)	Wald-type estimator OLS and IV Method 2 instruments: Closure to the mill and atmospheric stagnation	PM10 CO	Weekly attendance	Provo school district and Northridge School of Utha Valley Period: 1986 to 1987 Country: USA	Negative or no significant effect of CO school absence (no clear effect) But positive effect of PM10
MacNaughton et al. (2017)	Generalized linear models Poisson function	PM 2.5	percent of students chronically absent at school	1772 public schools in Massachusetts 2012-2013 academic year Country: USA	Positive impact of PM2.5 on school absence

Table A1: Pollution and school absenteeism

B Descriptive statistics

Table B1: Descriptive statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Absence	26143	0.06	0.24	0	1
PM 2.5	26143	117.47	67.45	16.06	221.42
Head education	23723	8.34	4.56	0	18
Head gender	26143	0.46	0.5	0	1
Child gender	26143	0.5	0.5	0	1
Child age	26143	9.89	3.08	5	15
Household size	26143	5.95	2.7	1	24
Presence of biological father=1	21505	0.39	0.49	0	1
Presence of biological mother=1	23785	0.75	0.43	0	1
Lack of teacher	25513	0.02	0.15	0	1
Wind speed in m/s	26143	3.32	0.39	2.94	4.33
Wind direction in degrees	26143	-59.87	65.08	-162.34	54.53
Temperature inversion	26143	-4.18	0.34	-4.41	-3.31
Rainfall in mm	26143	540.39	191.99	194.13	873.51
Year relative humidity	26143	51.7	8.49	39.37	68.13

C CF method framework

Consider the following structural equation:

$y_1 = z_1\omega_1 + \gamma_1 y_2 + u_1$ (1)

z is a vector of exogenous variables and y_2 is the endogenous variable.

The exogeneity of z is given by the following orthogonality condition:

$E(z_j' u_1) = 0$ (2)

with j=1,2...k et z=(z_1, z_2). Then, it is assumed that the elements of z are not perfectly collinear and thus the rank condition for (1) holds. Moreover, the rank condition is more easily stated in a linear form reduced by y_2 in the case of model 1. This linear form reduced by y_2 is as follows:

$y_2 = z\phi_2 + v_2 = z_1\phi_{21} + z_2\phi_{22} + v_2$ (3)

$E(z' v_2) = 0$ (4)

Furthermore, the rank condition is met in (1) if and only if $z_2\phi_{22}\#0$. This allows us to say there is an exogenous variable omitted from (1) which is partially correlated with y_2.

Therefore, there is a correlation between the structural error u_1 and the error of the reduced form v_2. One could therefore understand the "Function Control" approach through the following linear relation:

$u_1 = \rho_1 v_2 + e_1$ (5)

$E(v_2 e_1) = 0$ (6)

With $\rho_1 = E(v_2 u_1)/E(v_2^2)$ (7)

Furthermore, since u_1 and v_2 are not correlated with z then e_1 also is not correlated with z and y_2.

In the end, we obtain a new following valid equation by inserting (5) into (1):

$y_1 = z_1\omega_1 + \gamma_1 y_2 + \rho_1 v_2 + e_1$ (8)

In the CF method, v_2 in equation (8) is considered as a new explanatory variable. Its inclusion provides a new error term e_1 that is uncorrelated with other variables, including, y_2. Indeed, the presence of v_2 in the equation allows "controlling" the endogeneity of y_2. In other words, v_2 approximates the factors of u_1 that are correlated with y_2.

D Wealth index construction: Principal component analysis

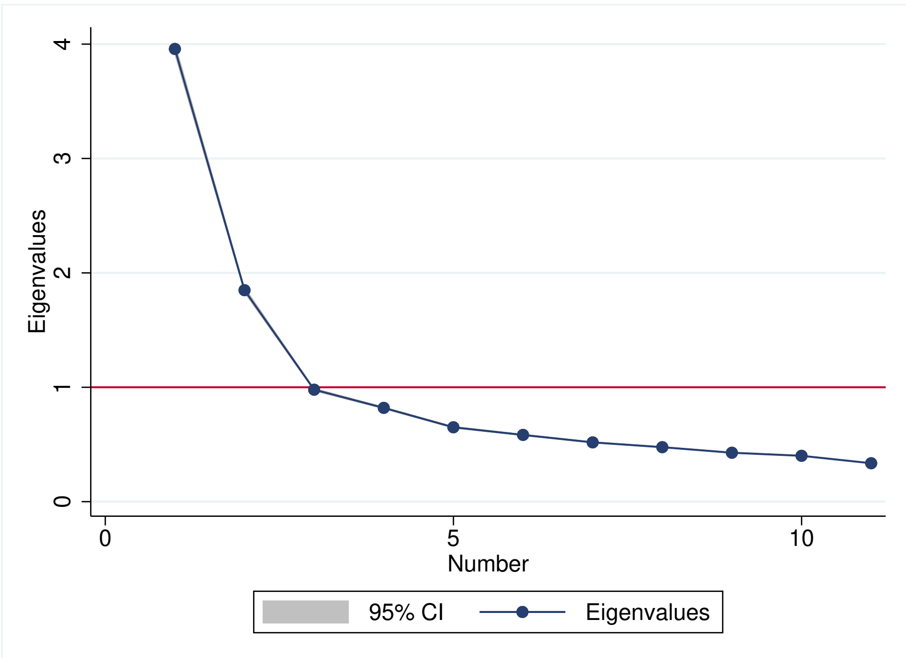

Figure D1: Components and eigenvalues

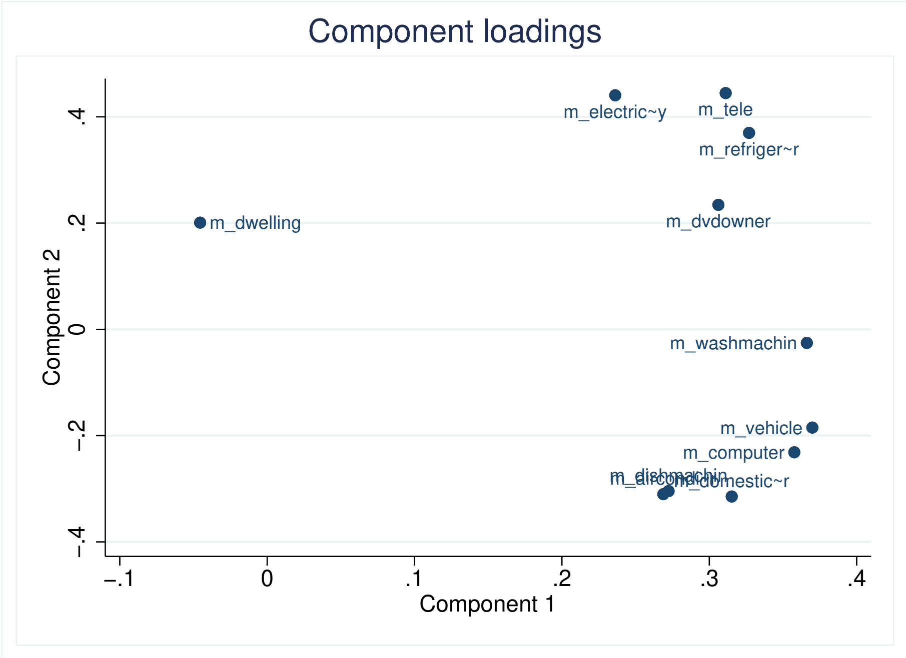

Figure D2: Selected components

E Data sources

Variables	Data sources
PM 2.5 concentration	van Donkelaar et al. (2018)
Socio-economic data	General Household Survey (Statistics South Africa, 2016, 2015, 2014) www.datafirst.uct.ac.za
Rainfall	Climatic Research Unit (CRU)
Temperature	ERA5 hourly data on pressure levels from 1979 to present. cds.climate.copernicus.eu
Humidity and Wind	ERA5 monthly mean data on single levels from 1979 to present. cds.climate.copernicus.eu

Chapter 5

Conclusion générale

Dans un contexte marqué par la dégradation du capital naturel, il est important de chercher à comprendre son impact sur le capital humain. Tous les pays ne sont pas exposés de la même manière aux conséquences de la dégradation du capital naturel. En effet, les pays en développement, surtout ceux de l'ASS, sont parmi les plus affectés. La dégradation du capital naturel comme la pollution de l'air, constitue un risque important pour la santé. Selon l'Organisation Mondiale de la Santé, la pollution de l'air ambiant et à l'intérieur des habitations est à l'origine, respectivement d'environ 339000 et 639000 décès prématurés en 2019 en Afrique. A la pollution de l'air se rajoute la déforestation qui affecte aussi la région, la réduction de la perte de couverture forestière restant faible en ASS par rapport aux régions du monde.

L'objectif de cette thèse est d'apporter un nouvel éclairage sur l'impact de la dégradation du capital naturel sur le capital humain en Afrique Subsaharienne. Trois études originales empiriques ont été réalisées et nous ont permis d'obtenir un certain nombre de résultats.

1 Principaux résultats et enseignements

Le chapitre 2 fournit une analyse détaillée de la relation entre la présence d'une aire protégée et le choix de combustible de cuisson en Côte d'Ivoire. Étant donné que la mise en place des aires protégées pourrait réduire la déforestation et affecter le statut économique des ménages aux alentours, l'objectif de l'étude est de savoir si cela conduirait à une transition énergétique vers les combustibles modernes plus propres ou à une utilisation simultanée des combustibles traditionnels et modernes par les ménages. Ce chapitre teste cette hypothèse en utilisant les données de l'enquête sur le niveau de vie des ménages ivoiriens de 2015 et la World Database on Protected Areas (WDPA). En raison de la structure des données qui sont au niveau des ménages et des sous-préfectures, nous utilisons un modèle logit multiniveaux à effets mixtes. En outre, au regard de la distribution non aléatoire des aires protégées, nous prenons en compte les caractéristiques de la sous-préfecture pouvant influencer la localisation des aires protégées. Cette étude est la première à s'intéresser à l'impact des aires protégées sur le choix de combustible de cuisson des ménages ivoiriens. Les résultats obtenus montrent qu'une hausse du coût d'accès à la forêt à travers la mise en place d'une aire protégée dans une sous-préfecture affecte le choix de combustible de cuisson des ménages vivant dans la localité. La présence de l'aire protégée augmente la probabilité d'utilisation de la biomasse achetée (bois de chauffe ou charbon de bois) par rapport à l'énergie propre (gaz) de 6,78 points de pourcentage. De plus, l'effet de la présence de l'aire protégée dépend du type et du niveau de protection de l'aire protégée, ainsi que de la zone de résidence. L'impact de l'aire protégée varie lorsqu'il s'agit d'un parc, d'une réserve naturelle ou d'une forêt classée. Lorsqu'il s'agit d'une aire protégée intégrale, cela augmente la probabilité d'utilisation de l'énergie propre (gaz). La présence d'une aire protégée dans une sous-préfecture peu développée augmente la probabilité d'utilisation de la biomasse collectée et quand il s'agit d'une zone urbaine, la présence de l'aire protégée augmente le risque d'utilisation de la biomasse achetée. Par ailleurs, certains facteurs, telles que les caractéristiques du chef de ménage et le statut socio-économique du ménage, affectent le choix du combustible de cuisson des ménages. Le cas de la Côte d'Ivoire est intéressant car le gouvernement a mis en place le Plan d'Action National des Energies Renouvelables dont certains objectifs spécifiques sont la préservation de la couverture forestière, l'augmentation de l'accès aux énergies propres et la réduction de la demande d'énergies polluantes plus précisément la réduction de la quantité de bois-énergies utilisée pour la satisfaction des besoins énergétiques des ménages (**?**). Toutefois, des efforts supplémentaires restent à fournir si le pays veut procurer l'énergie propre à la population à l'horizon 2030 et préserver la couverture forestière. Cette étude permet de contribuer à la littérature en fournissant des éléments de compréhension en ce qui concerne les conséquences de la mise en place des aires protégées en ASS. Au delà de la déforestation, la mise en place d'une aire protégée affecte le choix énergétique des ménages et donc la santé.

La pollution de l'air intérieur constitue un problème de santé publique dans les pays en développement, surtout en ASS où des combustibles solides (charbon et biomasse) sont utilisés pour les besoins énergétiques des ménages. Les femmes, qui sont habituellement responsables de la cuisine, et leurs jeunes enfants, sont les plus exposés à la pollution de l'air qui en résulte. L'objectif du chapitre 3 est d'analyser la relation causale entre la qualité de l'air intérieur et le risque de maladies respiratoires chez les individus en Côte d'Ivoire en fonction du groupe d'âge. En utilisant les données de l'enquête sur le niveau de vie des ménages de 2015 et la base de données satellites de van Donkelaar et al. (2018) qui contient les concentrations annuelles de particules fines au niveau du sol (PM2.5), nous créons un indicateur original de pollution de l'air intérieur pour approximer le niveau de pollution à laquelle les individus sont exposés quand ils sont à l'intérieur de la maison. Cet indicateur créé à partir des sources de pollution de l'air intérieur permet de combler le manque d'information sur la qualité de l'air intérieur dans la base de données. Les données sur la luminosité nocturne, provenant d'imagerie satellitaire issue de la base de données du Earth Observations Group, sont également utilisées et permettent d'avoir des informations sur le niveau de développement des sous-préfectures. L'étude est basée sur un échantillon de 2060 personnes qui avaient consulté un prestataire de soins de santé au cours des quatre dernières semaines au moment de l'enquête et réparties en quatre groupes d'âge. Les enfants de moins de 5 ans constituent le premier groupe. Le deuxième groupe est constitué d'enfants âgés de 5 à 14 ans. Le troisième groupe comprend les personnes âgées de 15 à 64 ans qui sont considérées comme des personnes actives. Enfin, le quatrième groupe est celui des personnes âgées de 65 ans et plus. Le rapport de dépendance est utilisé pour créer ces groupes d'âge afin de voir comment l'impact sanitaire de la pollution de l'air intérieur varie en fonction du groupe. Un modèle logit multiniveaux à effets mixtes est utilisé en raison de la structure des données qui sont au niveau des sous-préfectures, des ménages et individuel. Les résultats de l'étude montrent que la pollution de l'air intérieur augmente le risque de maladies respiratoires de 1.64% chez les enfants de moins de 5 ans. L'effet dépend de la présence de grands frères et soeurs âgés entre 5-15 ans, de la taille et de la zone de résidence du ménage. Il faut noter que cette étude est la première à répondre à cette question en utilisant un indicateur innovant de qualité de l'air intérieur dans un contexte d'indisponibilité de données sur la qualité de l'air intérieur sur le plan national, notamment dans un pays d'ASS telle que la Côte d'Ivoire.

Une meilleure qualité de l'air ambiant est importante pour la santé étant donné le temps passé à l'extérieur des maisons. D'après l'OMS, plus de 90 % des personnes vivent dans un endroit qui ne répond pas aux normes en matière de qualité de l'air et la partie du globe exposée à la pollution particulaire est essentiellement constituée de pays en développement (?). Le chapitre 4 s'intéresse à l'impact de la pollution de l'air ambiant sur l'absentéisme scolaire en Afrique du Sud, un pays dont l'air ambiant est de faible qualité. Le choix de l'Afrique du Sud est intéressant dans la mesure où le pays a mis en place depuis 2004 une politique de régulation de la qualité de l'air (2004 Air Quality Act). Parmi les polluants visés, il y a les particules fines (PM2.5) qui sont très néfastes pour la santé humaine et que nous utilisons pour approximer la qualité de l'air ambiant. Les PM2.5 sont à l'origine de la mortalité dues aux maladies respiratoires et cardiovasculaires. Celles-ci peuvent agir sur les performances économiques des pays, à travers leur impact sur le capital humain. Dans cette étude, nous nous intéressons particulièrement à l'absentéisme scolaire. Les analyses antérieures qui ont testé la relation entre la pollution aux particules et l'absentéisme scolaire trouvent un effet positif, négatif ou nul. A notre connaissance, cette étude est la première à s'intéresser à cette question dans le cas d'un pays d'ASS, les études précédentes étant focalisées sur les Etats-Unis, le Japon et la Corée du Sud. Les données de l'enquête générale des ménages de l'Afrique du Sud en 2015 et 2016 et les données de van Donkelaar et al. (2018) sur la concentration moyenne annuelle des PM2.5 sont utilisées. L'exposition des individus à la pollution de l'air n'est pas aléatoire car dépend de certains facteurs tels que les ressources financières qui pourraient affecter le choix de localisation des individus (Tiebout, 1956). La distribution non aléatoire de l'exposition à la pollution de l'air pourrait être à l'origine d'un problème d'endogénéité si nous utilisons directement les données de PM2.5. Dans le but d'éviter ce problème d'endogénéité dû au biais de variables omises, nous utilisons une méthode à variable instrumentale. Les instruments utilisés affectent la concentration des polluants dans l'atmosphère et sont la vitesse du vent, la direction du vent et le nombre d'épisodes d'inversion de température. Ces instruments sont extraits des images satellitaires de la NASA. L'épisode d'inversion de température est un phénomène qui implique une augmentation de la température avec l'altitude alors que la théorie indique le contraire. Pour obtenir l'information sur l'instrument, nous utilisons des pixels d'environ 25 km. Pour chaque pixel, nous faisons la différence entre la température quotidienne à 1000 hpa et la température à 925 hpa. La température à 1000 hpa correspond aux conditions de surface et la température à 925 hpa correspond aux conditions à environ 600 m au-dessus du niveau de la mer. Nous calculons ensuite pour chaque province le nombre de pixels où le résultat est négatif, c'est-à-dire où il y a eu une inversion de température. Cela permet d'obtenir le nombre d'épisodes d'inversion de température par province pour chaque année. Les résultats de l'étude révèlent qu'une augmentation de la concentration de PM2.5 de 10 $\mu g/m^3$ entraîne un risque d'absentéisme de 1,33 à 2,46 points de pourcentage chez les enfants âgés entre 5 et 15 ans. L'effet varie en fonction du niveau de richesse, de la taille du ménage, de la structure du ménage, et du sous-groupe de population (asiatiques, blancs, indiens, métissés, noirs) du chef de ménage. Ce chapitre contribue à la littérature en apportant une réponse claire quant à l'effet de la pollution de l'air ambiant sur l'absentéisme scolaire qui était jusqu'ici mitigé.

Les résultats et les enseignements de cette thèse devraient permettre de pousser la réflexion sur les conséquences de la dégradation du capital naturel et plus précisément sur le capital humain en ASS. Ils devraient orienter au mieux les politiques publiques afin d'atteindre les ODD 3, 7 et 13 d'ici 2030.

2 Pistes de recherches futures

Notre analyse de l'impact du capital naturel sur le capital humain fait face à certaines limites comme toute étude. La principale concerne l'indisponibilité de certaines informations dans les bases de données utilisées. Dans le chapitre 2, l'analyse de l'impact des aires protégées aurait été plus approfondie si nous avions l'information sur la localisation précise des ménages. Ces données nous auraient permis de prendre en compte la distance entre les ménages et les aires protégées. Si certaines données d'enquête le permettent, une idée à explorer serait d'étudier l'impact des aires protégées sur le choix de combustible des ménages en fonction de la distance qui les sépare de l'aire protégée.

Dans le cadre du chapitre 3, en raison de l'indisponibilité de données sur le niveau de pollution de l'air intérieur, nous utilisons un indicateur construit à partir des sources de pollution de l'air intérieur. La disponibilité d'une mesure directe aurait permis de quantifier avec plus de précision la qualité de l'air intérieur dans laquelle vit les ménages en Côte d'Ivoire. Afin d'étudier cet impact, les enquêtes futures sur le niveau de vie des ménages devrait prendre en compte cet aspect en collectant des données sur le niveau de pollution de l'air intérieur des ménages.

Dans le chapitre 4, l'indisponibilité de l'information sur la localisation géographique des ménages ne nous a pas permis de connaître le niveau exact de pollution de l'air ambiant auquel le ménage est exposé. De ce fait, nous utilisons le niveau de pollution de la province comme approximation. Étant donné que la plupart des enquêtes ménages sont géo-referencées, une idée de recherche future serait d'utiliser l'information sur la localisation des ménages afin d'obtenir le niveau précis de pollution de l'air ambiant.

Globalement, les résultats de cette thèse peuvent être utilisés par les agents des services statistiques pour améliorer les grandes enquêtes nationales sur les ménages. En permettant une meilleure exploitation future, les recommandations de politiques publiques seront améliorées.

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Chapter 6

Résumé extensif en français

1 Résumé extensif en français

L'Afrique subsaharienne (ASS), une région diverse et très riche en ressources naturelles, est composée de pays à revenu faible, moyen inférieur, moyen supérieur et élevé (World Bank Group, 2023). Malheureusement, cette partie de l'Afrique reste confrontée à plusieurs défis en matière de développement économique. Durant la période 1981-2020, la région a connu une tendance non linéaire de son taux de croissance. En effet, entre 1981-1995, le taux de croissance du Produit Intérieur Brut (PIB) par tête a baissé suivie d'une hausse entre 1996-2010. Le taux de croissance a ensuite chuté entre 2011-2015 et devient négatif durant le quinquennal 2016-2020. Entre 1981 et 2020, la baisse du taux de croissance du PIB par tête est plus élevée durant le quinquennal 1981-1985.

Les performances économiques de long terme en Afrique sont assez contrastées. La croissance est plus faible comparée à d'autres régions, notamment les pays de l'OCDE, vers la fin du 20e siècle. Cette faible performance économique est qualifiée de "tragique" par Artadi and Sala-i Martin (2003) car elle a eu d'énormes conséquences sur le bien-être humain dû à la hausse du niveau de pauvreté sur le continent. La baisse de croissance s'est suivie d'une phase d'amélioration au début des années 2000 comparativement à d'autres régions du monde. Cela a fait naître l'espoir d'un avenir économique meilleur pour le continent après des décennies de déclin (Rodrik, 2018). Ces phases contrastées de performances économiques de long terme suscitent une question importante: qu'est ce qui détermine le développement économique de la région ?

Artadi and Sala-i Martin (2003) listent les conditions pour que les économies africaines se développent. Il faudrait garantir la sécurité, mettre en place des institutions qui garantissent l'État de droit et les droits de propriété, investir dans le capital humain, réduire les distorsions politiques qui rendent les investissements excessivement coûteux, réduire des dépenses inutiles de l'Etat, et enfin s'ouvrir économiquement, ce qui favoriserait les flux de commerce, d'investissements directs étrangers (IDE) et de diffusion de technologie. Les auteurs soulignent la nécessité d'accumuler du capital humain pour une meilleure performance économique africaine. Cela est possible grâce aux investissements dans l'éducation et la santé de la population. De plus, selon les prévisions et les statistiques démographiques des Nations Unies, la population mondiale devrait atteindre environ 10,4 milliards d'individus d'ici la fin du siècle selon le scénario médian. Une bonne partie de cette croissance démographique mondiale aura lieu en Afrique car elle devrait atteindre environ 4 milliards d'individus d'ici 2100 soit environ 38% de la population mondiale et la population de l'ASS représentera à elle seule 32% de la population mondiale. Pour une meilleure performance économique de la région, il est plus que nécessaire de renforcer le capital humain en tirant profit du dividende démographique qui sera déterminant dans le développement économique du continent au 21e siècle.

Le capital humain est pris en compte dans les objectifs de Développement Durable (ODD). Nommés également objectifs mondiaux, les ODD ont été adoptés par les Nations Unies en 2015. Il s'agit d'un appel mondial à agir pour éradiquer la pauvreté, protéger la planète et faire en sorte que tous les êtres humains vivent dans la paix et la prospérité d'ici à 2030. De ce fait, les ODD comportent 17 objectifs dont cent-soixante-neuf cibles et deux cent trente indicateurs. Le capital humain est représenté à travers les troisième, septième et treizième ODD. En effet, ceux-ci s'intéressent respectivement à la préservation de la santé et le bien être de la population, à la fourniture d'une énergie propre et à un coût abordable, et la mise en place des mesures relatives à la lutte contre les changements climatiques d'ici 2030. Les préoccupations auxquelles ces 3 ODD devraient répondre sont très importantes pour le développement du capital humain des pays et surtout celui de l'ASS.

1.1 Contribution du capital humain et capital naturel au développement économique

Le terme "capital" provient de l'économie classique et néo-classique et définit un stock qui peut être organisé en classes appelées actifs et qui a le potentiel de produire d'autres biens ou utilités au profit des sociétés humaines (Ekins et al., 2003; Mace et al., 2015). Il existe trois grands types de capital: le capital humain, le capital manufacturé ou produit et le capital naturel.

Le Produit Interieur Brut (PIB), un indicateur important de l'activité économique, est une mesure de flux qui saisit le revenu ou la production sur une période donnée. Cet indicateur présente une limite car il ne reflète pas la dépréciation, l'épuisement et la dégradation des actifs utilisés. Par conséquent, utilisé seul, le PIB peut fournir des signaux trompeurs sur l'état de l'économie, l'efficacité de l'utilisation des actifs et la durabilité du développement. C'est dans ce sens que la Banque Mondiale a mis en place un indicateur de la richesse totale des nations qui est la somme du capital produit, du capital humain, du capital naturel et des avoirs étrangers nets. Ainsi, pour évaluer les performances économiques d'un pays, il est important de suivre à la fois le PIB et la richesse totale.

Le capital naturel est la valeur combinée de tout ce qui provient de la nature. Il regroupe entre autres les créatures vivantes, l'eau, l'air et le sol, et procure aux êtres humains les moyens essentiels dont ils ont besoin pour vivre. Le capital naturel est créé par des processus biogéophysiques plutôt que par l'action humaine et représente la capacité de l'environnement à répondre aux besoins humains, que ce soit en fournissant des matières premières ou des services (Hamilton and Clemens, 1999; Natural Capital Committee and others, 2013). Ces services comprennent les cycles biochimiques mondiaux dans le maintien des conditions écologiques propices à la vie humaine (Hamilton and Clemens, 1999). Ainsi, le capital naturel produit des intrants productifs qui, combinés aux intrants humains et produits, génèrent des biens qui procurent des avantages de valeur à la société (Edens and Hein, 2013; Mace et al., 2015).

Par ailleurs, selon la Banque Mondiale, *le capital humain correspond à l'ensemble des connaissances, compétences et conditions de santé que les individus accumulent tout au long de leur vie et qui leur permet de réaliser pleinement leur potentiel en devenant des membres productifs de la société*. Cette définition révèle que les composantes essentielles du capital humain sont la santé et l'éducation. En effet, la théorie du capital humain se concentre non seulement sur l'éducation mais aussi sur la santé de l'individu en tant qu'intrant de la production économique (Osiobe et al., 2019). Ainsi, le capital humain est considéré comme un facteur de production qui, combiné au capital physique (Mincer, 1984), est essentiel pour la croissance économique de nos pays.

La contribution du capital naturel et du capital humain dans la richesse totale des pays est indéniable et varie selon les régions entre 1995 et 2018 (Figure 1.4). Le capital humain constitue une part importante qui augmente au cours du temps et représente plus de 50% de la richesse totale dans certaines régions. Cette tendance est également observée en ASS, où on observe une hausse de la part du capital humain sur la période. Par contre, la part du capital naturel tend à baisser au cours du temps sauf dans la région du Moyen Orient et Afrique du Nord où le capital naturel représente 38% de la richesse totale. Le capital humain et le capital naturel combinés représentent en moyenne environ 72% de la richesse totale dans le monde. Ils contribuent fortement au développement économique des pays.

1.2 Démographie, capital humain et développement économique

La population totale de l'ASS devrait atteindre environ 3,5 milliards d'individus d'ici la fin du siècle. Cette taille estimée de la population offre un dividende démographique favorable à la croissance économique à travers le renforcement du capital humain. Le dividende démographique est défini comme le bénéfice de l'augmentation de la part de la population active. Il s'agit donc d'une période propice pour investir dans la santé et l'éducation et développer ainsi le capital humain. Pour profiter pleinement du dividende démographique en ASS, les politiques de renforcement du capital humain doivent être suivies par des politiques de création d'emplois pour la population active sans quoi les espoirs de développement qu'il suscite ne peuvent que rester vains.

Le capital humain reste limité dans la région (World Bank Group, 2023). En effet, d'après le nouvel indice de capital humain mis au point par la Banque Mondiale qui mesure le niveau de productivité potentielle de la prochaine génération de travailleurs, l'ASS a l'indice le plus faible parmi toutes les régions du monde. En 2020, la moyenne de l'indice est estimée à 0,4 ce qui est inférieur à la moyenne mondiale de 0,56. La valeur de l'indice montre que dans l'état actuel des choses, un enfant né en 2020 en ASS à l'âge adulte ne pourrait espérer atteindre que 40% seulement de son niveau de productivité s'il bénéficiait d'une éducation complète et d'une santé totale. Il existe une disparité à l'intérieur du continent africain car l'Afrique du Nord et de l'Est se distinguent avec une valeur de l'indice supérieure à la moyenne de l'ASS. Au regard de l'importance du capital humain dans la richesse totale des nations, son faible niveau agit directement sur le bien-être des individus et sur l'économie des pays en ASS.

Selon le rapport de la Banque Mondiale sur le "Africa Human Capital Plan" (The World Bank, 2019), la faiblesse du capital humain en ASS s'expliquerait par la mortalité infantile et maternelle, l'éducation et la malnutrition. Le point commun de ces facteurs est le niveau de pauvreté qui reste élevé dans la région. Cela se traduit par une dépendance de la population de l'ASS au capital naturel.

1.3 Dégradation du capital naturel

Les enjeux environnementaux suite à la dégradation du capital naturel sont de plus en plus importants. La surexploitation du capital naturel entraîne de nombreux dommages environnementaux qui augmentent plus rapidement que prévu (PNUE, 2017). Cela se traduit entre autres par le changement climatique, l'érosion des sols, la pollution de l'air, la perte de la biodiversité et des habitats sauvages tels que les forêts et les zones humides. La dégradation du capital naturel impose des coûts externes à la société et aux générations futures. Dans le cadre de cette thèse nous nous intéressons spécifiquement à la pollution de l'air et à la déforestation. Les lignes suivantes donnent un aperçu de l'état des lieux en ce qui concerne la qualité de l'air et la perte de la couverture forestière en ASS.

La pollution de l'air

Selon l'Organisation Mondiale de la Santé (OMS), "la pollution de l'air est la contamination de l'environnement intérieur ou extérieur par tout agent chimique, physique ou biologique qui modifie les caractéristiques naturelles de l'atmosphère" (Organisation Mondiale de la Santé, 2024). Les polluants les plus néfastes pour la santé humaine sont les particules en suspension, le monoxyde de carbone, l'ozone, le dioxyde d'azote et le dioxyde de soufre. Les sources de pollution atmosphérique les plus fréquentes sont les véhicules à moteur, les appareils à combustion d'usage domestique, les installations industrielles et les incendies de forêt.

En ce qui concerne la pollution de l'air ambiant, toutes les régions terrestres ne sont pas exposées au même niveau de pollution. Bien que l'on constate une tendance à la baisse du niveau d'exposition aux particules fines (PM2.5) entre 2015 et 2019 dans le monde, l'ASS continue d'enregistrer un niveau d'exposition aux particules fines (PM2.5) plus élevé que le niveau mondial entre 2015 et 2019. Ce niveau de pollution n'est pas sans conséquence sur la santé des individus car il est à l'origine de maladies respiratoires, cardiovasculaires et autres, et constitue une cause importante de morbidité et de mortalité. Selon l'OMS, la quasi-totalité de la population mondiale (99%) respire un air pollué.

En plus de la pollution de l'air ambiant, la pollution de l'air intérieur constitue également un problème majeur de santé publique. Elle est générée par l'utilisation de combustibles et de technologies inefficaces et polluants à l'intérieur et autour des habitations. Elle contient des polluants nocifs pour la santé, notamment de petites particules qui pénètrent profondément dans les poumons et s'infiltrent dans la circulation sanguine. Selon l'OMS, dans les habitations moins ventilées, la fumée intérieure peut contenir des niveaux de particules fines 100 fois supérieurs au niveau acceptable (Organisation Mondiale de la Santé, 2023a). Les femmes généralement responsables des tâches ménagères telles que la cuisine et la collecte de bois de chauffage, sont les plus exposés à la pollution de l'air intérieur ainsi que les enfants. Ce type de pollution est à l'origine des maladies non transmissibles telles que le cancer du poumon, les cardiopathies ischémiques, les broncho-pneumopathies chroniques obstructives et les accidents vasculaires cérébraux (Organisation Mondiale de la Santé, 2023a).

La perte de la couverture forestière

La superficie forestière mondiale est estimée à 4,06 milliards d'hectares (ha), ce qui équivaut à 31% de la superficie totale des terres (FAO, 2020). Les cinq pays qui abritent plus de la moitié (54%) des forêts mondiales sont la Russie, le Brésil, le Canada, les États-

Unis d'Amérique et la Chine (FAO, 2020). Depuis 1990, le monde a perdu 178 millions d'hectares de forêts, même si le rythme des pertes a diminué entre 1990 et 2020. En effet, la perte forestière est passée de 7,8 millions ha par an entre 1990-2000 à 5,2 millions ha par an entre 2000-2010 et à 4,7 million ha par an lors de la décennie 2010-2020. Ces chiffres montrent une diminution de la perte forestière qui pourrait s'expliquer par la baisse de la déforestation dans certains pays et l'augmentation de la superficie forestière dans d'autres grâce au boisement et à l'expansion naturelle des forêts (FAO, 2020).

Malgré la réduction de la perte de la couverture forestière au niveau mondial, elle reste faible en Afrique par rapport aux autres régions. Le graphique montre qu'au cours de la récente décennie (2010-2020), l'Afrique enregistre le taux annuel de perte nette de forêts le plus élevé avec 3,9 millions d'hectares, suivie par l'Amérique du Sud, avec 2,6 millions d'hectares. Nous observons cette tendance à la hausse du taux annuel de perte nette de forêts en Afrique au cours de chacune des trois décennies depuis 1990 par rapport aux autres régions. Cela montre une accentuation de la déforestation en Afrique depuis 1990.

Dans la région africaine, les causes de la déforestation sont nombreuses et variées. Elles concernent principalement les activités agricoles, l'agro-industrie, les activités minières, l'urbanisation et la demande en bois-énergie. Ce dernier facteur constitue un facteur très important de la déforestation car les ménages africains sont très dépendants de la biomasse. En effet, la proportion de la population africaine qui utilise la biomasse (bois de chauffe, charbon de bois) pour cuisiner est d'environ 60% en 2021. Entre 1990-2021, dans presque toutes les régions du monde, il y a une tendance à la baisse en ce qui concerne l'utilisation de la biomasse pour la cuisine. L'Afrique enregistre toutefois une baisse relativement faible. La région a encore du chemin à faire pour diminuer l'utilisation de la biomasse de cuisson et ralentir la déforestation d'une part et préserver la santé des ménages d'autre part.

La section suivante s'intéresse à la relation entre la capital naturel et le capital humain.

1.4 Dégradation du capital naturel et capital humain

La dégradation du capital naturel affecte le capital humain, notamment, la pollution de l'air (Kampa and Castanas, 2008; Carson, 2010; Graff Zivin, 2012, 2013; Hanna, 2015). La pollution atmosphérique constitue l'un des grands risques pour la santé liée à l'environnement. En effet, la pollution de l'air ambiant et à l'intérieur des habitations est à l'origine respectivement d'environ 339000 et 639000 décès prématurés en 2019 en Afrique (Organisation Mondiale de la Santé, 2023b).

L'exposition des individus à la pollution de l'air n'est pas aléatoire car elle dépend de plusieurs facteurs. En ASS, le facteur essentiel constitue les ressources financières. En effet, l'extrême pauvreté sévit dans la région car environ 462 millions de personnes y sont encore exposées en 2023 (World Bank Group, 2023). Ce niveau de pauvreté pousse la population à être très dépendante et exposée au capital naturel. Ainsi, la pauvreté peut affecter entre autres le choix de combustible des ménages ou le choix du lieu de résidence. Les contraintes financières peuvent conduire un ménage à utiliser un combustible polluant comme la biomasse végétale qu'il peut acheter à moindre coût ou collecter directement dans les forêts. Selon Dagnachew et al. (2020), près de 900 millions de personnes en ASS utilisent la biomasse végétale pour cuisiner. L'utilisation de ce genre de combustible constitue une source de pollution de l'air intérieur si la combustion est incomplète et a des répercussions sur la biodiversité, le climat et la santé.

D'après l'OMS, les décès provoqués par la mauvaise qualité de l'air intérieur sont dus à des cardiopathies ischémiques (32%), à des infections des voies respiratoires inférieures (21%), à des accidents vasculaires cérébraux (23%), à des bronchopneumopathies chroniques obstructives (19%) et à des cancers du poumon (6%). Les enfants de moins de 5 ans ne sont pas épargnés car leur exposition à la pollution de l'air domestique est responsable de près de la moitié des décès par pneumonie. L'exposition peut également être à l'origine d'un faible poids à la naissance, d'asthme, d'otites, d'infections des voies respiratoires supérieures, de tuberculose, de cataracte, de cancers du nasopharynx et du larynx, et de cancer du col de l'utérus. Ce type de pollution était responsable d'environ 3,2 millions de décès par an en 2020 dans le monde, dont plus de 237 000 décès d'enfants de moins de 5 ans (Organisation Mondiale de la Santé, 2023a). Les effets combinés de la pollution de l'air ambiant et de la pollution de l'air domestique sont associés à 6,7 millions de décès prématurés par an dans le monde (Organisation Mondiale de la Santé, 2023a). Il est donc primordial de développer l'utilisation de combustibles et de technologies propres pour réduire la pollution de l'air dans les habitations et protéger la santé. Il s'agit notamment de l'énergie solaire, de l'électricité, du biogaz, du gaz de pétrole liquéfié (GPL), du gaz naturel, des carburants à base d'alcool, ainsi que des fourneaux à biomasse qui respectent les objectifs d'émission fixés par les normes de l'OMS (Organisation Mondiale de la Santé, 2023a). La Côte d'Ivoire, pays auquel nous nous intéressons dans la thèse pour traiter ce sujet, tente de diminuer au maximum l'utilisation des combustibles polluants et de préserver ainsi la couverture forestière à l'horizon 2030 à travers le Plan d'Actions National des Energies Renouvelables (PANER) (Ministère du Pétrole et de l'Energie, 2016).

Les ressources financières constituent l'un des facteurs qui peut affecter le choix de localisation des ménages (Tiebout, 1956). De ce fait, le manque de moyens financiers peut les inciter à choisir des zones où les logements coûtent moins cher et ces zones pourraient se caractériser par une mauvaise qualité de l'air ambiant. Parmi les pays exposés à la pollution de l'air ambiant en ASS, l'Afrique du Sud n'est pas un bon élève. Son niveau de pollution de l'air ambiant s'expliquerait par le développement des industries surtout extractives et la densité du trafic routier. Pour pallier ce problème de pollution de l'air, le pays a mis en place depuis 2004 une politique de régulation de la qualité de l'air (2004 Air Quality Act). Parmi les polluants visés figurent les particules fines (PM 2.5) qui sont très néfastes pour la santé humaine.

Cependant, le lien entre le capital naturel et le capital humain en ASS n'est pas suffisamment étudié. Ce besoin de connaissances est plus que nécessaire pour définir les bonnes politiques publiques. Ainsi, l'objectif des travaux de cette thèse est de contribuer à la littérature sur la relation qui existe entre le capital humain et le capital naturel et quantifier ainsi les différents impacts socio-économiques de la dégradation du capital naturel en ASS.

1.5 Contribution de la thèse

Les travaux conduits dans le cadre de cette thèse s'intéressent à l'impact du capital naturel sur le capital humain en ASS. La thèse se décline en 3 chapitres originaux.

Le chapitre 2 fournit une analyse détaillée de la relation entre la présence d'une aire protégée et le choix de combustible de cuisson en Côte d'Ivoire. Étant donné que la mise en place des aires protégées pourrait réduire la déforestation et affecter le statut économique des ménages aux alentours, l'objectif de l'étude est de savoir si cela conduirait à une transition énergétique vers les combustibles modernes plus propres ou à une utilisation simultanée des combustibles traditionnels et modernes par les ménages. Ce chapitre teste cette hypothèse en utilisant les données de l'enquête sur le niveau de vie des ménages ivoiriens de 2015 et la World Database on Protected Areas (WDPA) qui sont des données satellites. En raison de la structure des données qui sont au niveau des ménages et des sous-préfectures, nous utilisons un modèle logit multiniveaux à effets mixtes. En outre, au regard de la distribution non aléatoire des aires protégées, nous prenons en compte les caractéristiques de la sous-préfecture pouvant influencer la localisation des aires protégées. Cette étude est la première à s'intéresser à l'impact des aires protégées sur le choix de combustible de cuisson des ménages ivoiriens. Les résultats obtenus montrent qu'une hausse du coût d'accès à la forêt à travers la mise en place d'une aire protégée dans une sous-préfecture affecte le choix de combustible de cuisson des ménages vivant dans la localité. La présence de l'aire protégée augmente la probabilité d'utilisation de la biomasse achetée (bois de chauffe ou charbon de bois) par rapport à l'énergie propre (gaz) de 6,78 points de pourcentage. De plus, l'effet de la présence de l'aire protégée dépend du type et du niveau de protection de l'aire protégée, ainsi que de la zone de résidence. L'impact de l'aire protégée varie lorsqu'il s'agit d'un parc, d'une réserve naturelle ou d'une forêt classée. Lorsqu'il s'agit d'une aire protégée intégrale, cela augmente la probabilité d'utilisation de l'énergie propre (gaz). La présence d'une aire protégée dans une sous-préfecture peu développée augmente la probabilité d'utilisation de la biomasse collectée et quand il s'agit d'une zone urbaine, la présence de l'aire protégée augmente le risque d'utilisation de la biomasse achetée. Par ailleurs, certains facteurs, tels que les caractéristiques du chef de ménage et le statut socio-économique du ménage, affectent le choix du combustible de cuisson des ménages. Le cas de la Côte d'Ivoire est intéressant car le gouvernement a mis en place le Plan d'Action National des Energies Renouvelables dont certains objectifs spécifiques sont la préservation de la couverture forestière, l'augmentation de l'accès aux énergies propres et la réduction de la demande d'énergies polluantes plus précisément la réduction de la quantité de bois-énergies utilisée pour la satisfaction des besoins énergétiques des ménages (Ministère du Pétrole et de l'Energie, 2016). Toutefois, des efforts supplémentaires restent à fournir si le pays veut procurer l'énergie propre à la population à l'horizon 2030 et préserver la couverture forestière. Cette étude permet de contribuer à la littérature en fournissant des éléments de compréhension en ce qui concerne les conséquences de la mise en place des aires protégées en ASS. Au delà de la déforestation, la mise en place d'une aire protégée affecte le choix énergétique des ménages et donc la santé.

La pollution de l'air intérieur constitue un problème de santé publique dans les pays en développement et surtout en ASS où des combustibles solides (charbon et biomasse) sont utilisés pour les besoins énergétiques des ménages. Les femmes, qui sont habituellement responsables de la cuisine, et leurs jeunes enfants, sont les plus exposés à la pollution de l'air qui en résulte. L'objectif du chapitre 3 est d'analyser la relation causale entre la qualité de l'air intérieur et le risque de maladies respiratoires chez les individus en Côte d'Ivoire en fonction du groupe d'âge. En utilisant les données de l'enquête sur le niveau de vie des ménages de 2015 et la base de données satellites de van Donkelaar et al. (2018) qui contient les concentrations annuelles de particules fines au niveau du sol (PM2.5), nous créons un indicateur original de pollution de l'air intérieur pour approximer le niveau de pollution à laquelle les individus sont exposés quand ils sont à l'intérieur de la maison. Cet indicateur créé à partir des sources de pollution de l'air intérieur permet de combler le manque d'information sur la qualité de l'air intérieur dans la base de données. Les données sur la luminosité nocturne, provenant d'imagerie satellitaire issue de la base de données du Earth Observations Group, sont également utilisées et permettent d'avoir des informations sur le niveau de développement des sous-préfectures. L'étude est basée sur un échantillon de 2060 personnes qui avaient consulté un prestataire de soins de santé au cours des quatre dernières semaines au moment de l'enquête et réparties en quatre groupes d'âge. Les enfants de moins de 5 ans constituent le premier groupe. Le deuxième groupe est constitué d'enfants âgés de 5 à 14 ans. Le troisième groupe comprend les personnes âgées de 15 à 64 ans qui sont considérées comme des personnes actives. Enfin, le quatrième groupe est celui des personnes âgées de 65 ans et plus. Le rapport de dépendance est utilisé pour créer ces groupes d'âge afin de voir comment l'impact sanitaire de la pollution de l'air intérieur varie en fonction du groupe. Un modèle logit multiniveaux à effets mixtes est utilisé en raison de la structure des données qui sont au niveau des sous-préfectures, des ménages et individuel. Les résultats de l'étude montrent que la pollution de l'air intérieur augmente le risque de maladies respiratoires de 1.64% chez les enfants de moins de 5 ans. L'effet dépend de la présence de grands frères et soeurs âgés entre 5-15 ans, de la taille et de la zone de résidence du ménage. Cette étude est la première à répondre à cette question en utilisant un indicateur innovant de qualité de l'air intérieur pour pallier l'indisponibilité des données au niveau national dans un pays d'ASS comme la Côte d'Ivoire.

Une meilleure qualité de l'air ambiant est importante pour la santé étant donné le temps passé à l'extérieur des maisons. D'après l'OMS, plus de 90 % des personnes vivent dans un endroit qui ne répond pas aux normes en matière de qualité de l'air et la partie du globe exposée à la pollution particulaire est essentiellement constituée de pays en développement (World Health Organization, 2016). Le chapitre 4 s'intéresse à l'impact de la pollution de l'air ambiant sur l'absentéisme scolaire en Afrique du Sud, pays dont l'air ambiant n'est pas de très bonne qualité. Le choix de l'Afrique du Sud est intéressant dans la mesure où le pays a mis en place depuis 2004 une politique de régulation de la qualité de l'air (2004 Air Quality Act). Parmi les polluants visés, il y a les particules fines (PM2.5) qui sont très néfastes pour la santé humaine et que nous utilisons pour approximer la qualité de l'air ambiant. Les PM2.5 sont à l'origine de la mortalité due aux maladies respiratoires et cardiovasculaires. Celles-ci peuvent agir sur les performances économiques des pays, à travers leur impact sur le capital humain. Dans cette étude, nous nous intéressons particulièrement à l'absentéisme scolaire. Les analyses antérieures qui ont testé la relation entre la pollution aux particules et l'absentéisme scolaire trouvent un effet positif, négatif ou nul. A notre connaissance, cette étude est la première à s'intéresser à cette question dans le cas d'un pays d'ASS, les études précédentes étant focalisées sur les Etats-Unis, le Japon et la Corée du Sud. Les données de l'enquête générale des ménages de l'Afrique du Sud en 2015 et 2016 et les données de van Donkelaar et al. (2018) sur la concentration moyenne annuelle des PM2.5 sont utilisées. L'exposition des individus à la pollution de l'air n'est pas aléatoire car dépend de certains facteurs tels que les ressources financières qui pourraient affecter le choix de localisation des individus (Tiebout, 1956). La distribution non aléatoire de l'exposition à la pollution de l'air pourrait être à l'origine d'un problème d'endogénéité si nous utilisons directement les données de PM2.5. Dans le but d'éviter ce problème d'endogénéité dû au biais de variables omises, nous utilisons une méthode à variable instrumentale. Les instruments utilisés affectent la concentration des polluants dans l'atmosphère et sont la vitesse du vent, la direction du vent et le nombre d'épisodes d'inversion de température. Ces instruments sont extraits des images satellitaires de la NASA. L'épisode d'inversion de température est un phénomène qui implique une augmentation de la température avec l'altitude alors que la théorie indique le contraire. Pour obtenir l'information sur l'instrument, nous utilisons des pixels d'environ 25 km. Pour chaque pixel, nous faisons la différence entre la température quotidienne à 1000 hpa et la température à 925 hpa. La température à 1000 hpa correspond aux conditions de surface et la température à 925 hpa correspond aux conditions à environ 600 m au-dessus du niveau de la mer. Nous calculons ensuite pour chaque province le nombre de pixels où le résultat est négatif, c'est-à-dire où il y a eu une inversion de température. Cela permet d'obtenir le nombre d'épisodes d'inversion de température par province pour chaque année. Les résultats de l'étude révèlent qu'une augmentation de la concentration de PM2.5 de 10 $\mu g/m^3$ entraîne un risque d'absentéisme de 1,33 à 2,46 points de pourcentage chez les enfants âgés entre 5 et 15 ans. L'effet varie en fonction du niveau de richesse, de la taille du ménage, de la structure du ménage, et du sous-groupe de population (asiatiques, blancs, indiens, métissés, noirs) du chef de ménage. Ce chapitre contribue à la littérature en apportant une réponse claire quant à l'effet de la pollution de l'air ambiant sur l'absentéisme scolaire qui était jusqu'ici mitigé.

Les résultats et les enseignements de cette thèse devraient permettre de pousser la réflexion sur les conséquences de la dégradation du capital naturel, plus précisément sur le capital humain en ASS. Ils devraient orienter au mieux les politiques publiques afin d'atteindre les ODD 3, 7 et 13 d'ici 2030.

1.6 Pistes de recherches futures

Notre analyse de l'impact du capital naturel sur le capital humain fait face à certaines limites comme toute étude. La principale concerne l'indisponibilité de certaines informations dans les bases de données utilisées. Dans le chapitre 2, l'analyse de l'impact des aires protégées aurait été plus approfondie si nous avions l'information sur la localisation précise des ménages. Ces données nous auraient permis de prendre en compte la distance entre les ménages et les aires protégées. Si certaines données d'enquête le permettent, une idée à explorer serait d'étudier l'impact des aires protégées sur le choix de combustible des ménages en fonction de la distance qui les sépare de l'aire protégée.

Dans le cadre du chapitre 3, en raison de l'indisponibilité de données sur le niveau de pollution de l'air intérieur, nous utilisons un indicateur construit à partir des sources de pollution de l'air intérieur. La disponibilité d'une mesure directe aurait permis de quantifier avec plus de précision la qualité de l'air intérieur dans laquelle vit les ménages en Côte d'Ivoire. Afin d'étudier cet impact, les enquêtes futures sur le niveau de vie des ménages devrait prendre en compte cet aspect en collectant des données sur le niveau de pollution de l'air intérieur des ménages.

Dans le chapitre 4, l'indisponibilité de l'information sur la localisation géographique des ménages ne nous a pas permis de connaître le niveau exact de pollution de l'air ambiant auquel le ménage est exposé. De ce fait, nous utilisons le niveau de pollution de la province comme approximation. Étant donné que la plupart des enquêtes ménages sont géo-referencées, une idée de recherche future serait d'utiliser l'information sur la localisation des ménages afin d'obtenir le niveau précis de pollution de l'air ambiant.

Globalement, les résultats de cette thèse peuvent être utilisés par les agents des services statistiques pour améliorer les grandes enquêtes nationales sur les ménages. En permettant une meilleure exploitation future, les recommandations de politiques publiques seront améliorées.

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