Onzième article : **Forestry biomass potential for energy production at global scale: a systematic review**

Par : R. O. Balagueman, E. S. P. Assede, O. Hidirou, M. Agassounon, E. B. Ayihouenou, S. M. D. Kinnoume, I. Moumouni-Moussa, A. K. Natta and H. S. S. Biaou

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Informations générales

Le Bulletin de la Recherche Agronomique du Bénin (BRAB) édité par l'Institut National des Recherches Agricoles du Bénin (INRAB) est un organe de publication créé en mai 1991 pour offrir aux chercheurs béninois et étrangers un cadre pour la diffusion des résultats de leurs travaux de recherche. Il accepte des articles originaux de recherche et de synthèse, des contributions scientifiques, des articles de revue, des notes et fiches techniques, des études de cas, des résumés de thèse, des analyses bibliographiques, des revues de livres et des rapports de conférence relatifs à tous les domaines de l'agronomie et des sciences apparentées, ainsi qu'à toutes les disciplines du développement rural. La publication du Bulletin est assurée par un comité de rédaction et de publication appuyés par un conseil scientifique qui réceptionne les articles et décide de l'opportunité de leur parution. Ce comité de rédaction et de publication est appuyé par des comités de lecture qui sont chargés d'apprécier le contenu technique des articles et de faire des suggestions aux auteurs afin d'assurer un niveau scientifique adéquat aux articles. La composition du comité de lecture dépend du sujet abordé par l'article proposé. Rédigés en français ou en anglais, les articles doivent être assez informatifs avec un résumé présenté dans les deux langues, dans un style clair et concis. Une note d'indications aux auteurs est disponible dans chaque numéro et peut être obtenue sur demande adressée au secrétariat du BRAB. Pour recevoir la version électronique pdf du BRAB, il suffit de remplir la fiche d'abonnement et de l'envoyer au comité de rédaction avec les frais d'abonnement. La fiche d'abonnement peut être obtenue à la Direction Générale de l'INRAB, dans ses Centres de Recherches Agricoles ou à la page vii de tous les numéros. Le BRAB publie par an normalement deux (02) numéros en juin et décembre mais quelquefois quatre (04) numéros en mars, juin, septembre et décembre et aussi des numéros spéciaux mis en ligne sur le site web : http://www.inrab.org. Pour les auteurs, une contribution de cinquante mille (50.000) Francs CFA est demandée par article soumis et accepté pour publication. L'auteur principal reçoit la version électronique pdf du numéro du BRAB contenant son article.

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Indications aux auteurs

Types de contributions et aspects généraux

Le Bulletin de la Recherche Agronomique du Bénin (BRAB) accepte des articles scientifiques, des articles de synthèse, des résumés de thèse de doctorat, des analyses bibliographiques, des notes et des fiches techniques, des revues de livres, des rapports de conférences, d'ateliers et de séminaires, des articles originaux de recherche et de synthèse, puis des études de cas sur des aspects agronomiques et des sciences apparentées produits par des scientifiques béninois ou étrangers. La responsabilité du contenu des articles incombe entièrement à l'auteur et aux co-auteurs. Le BRAB publie par an normalement deux (02) numéros en juin et décembre mais quelquefois quatre (04) numéros en mars, juin, septembre et décembre et aussi des numéros spéciaux mis en ligne sur le site web : http://www.inrab.org. Pour les auteurs, une contribution de cinquante mille (50.000) Francs CFA est demandée par article soumis et accepté pour publication. L'auteur principal reçoit la version électronique pdf du numéro du BRAB contenant son article.

Soumission de manuscrits

Les articles doivent être envoyés par voie électronique par une lettre de soumission (*covering letter*) au comité de rédaction et de publication du BRAB aux adresses électroniques suivantes : *E-mail : brabpisbinrab@gmail.com.* Dans la lettre de soumission les auteurs doivent proposer l'auteur de correspondance ainsi que les noms et adresses (y compris les e-mails) de trois (03) experts de leur discipline ou domaine scientifique pour l'évaluation du manuscrit. Certes, le choix des évaluateurs (*referees*) revient au comité éditorial du Bulletin de la Recherche Agronomique du Bénin. Les manuscrits doivent être écrits en français ou en anglais, tapé/saisi sous Winword ou Word ou Word docx avec la police Arial taille 10 en interligne simple sur du papier A4 (21,0 cm x 29,7 cm). L'auteur doit fournir des fichiers électroniques des illustrations (tableaux, figures et photos) en dehors du texte. Les figures doivent être réalisées avec un logiciel pour les graphiques. Les données ayant servi à élaborer les figures seront également fournies. Les photos doivent être suffisamment contrastées. Les articles sont soumis par le comité de rédaction à des évaluateurs, spécialistes du domaine.

Sanction du plagiat et de l'autoplagiat dans tout article soumis au BRAB pour publication

De nombreuses définitions sont données au plagiat selon les diverses sources de documentations telles que « -i- Acte de faire passer pour siens les textes ou les idées d'autrui. -ii- Consiste à copier les autres en reprenant les idées ou les résultats d'un autre chercheur sans le citer et à les publier en son nom propre. -iii- Copie frauduleuse d'une œuvre existante en partie ou dans sa totalité afin de se l'approprier sans accord préalable de l'auteur. -iv- Vol de la création originale. -v- Violation de la propriété intellectuelle d'autrui. » (https://integrite.umontreal.ca/reglements/definitions-generales/). Le Plagiat et l'Autoplagiat sont à bannir dans les écrits scientifiques. Par conséquent, tout article soumis pour sa publication dans le BRAB doit être préalablement soumis à une analyse de plagiat, en s'appuyant sur quelques plateformes de détection de plagiat. Le **plagiat constaté dans tout article** sera sanctionné par un retour de l'article accompagné du **rapport de vérification du plagiat par un logiciel antiplagiat** à l'auteur de correspondance pour sa correction avec **un taux de tolérance de plagiat ou de similitude inférieur ou égal à sept pour cent (07%)**.

Respecter de certaines normes d'édition et règles de présentation et d'écriture

Pour qu'un article soit accepté par le comité de rédaction, il doit respecter certaines normes d'édition et règles de présentation et d'écriture. Ne pas oublier que les trois (3) **qualités fondamentales d'un article scientifique** sont la **précision** (supprimer les adjectifs et adverbes creux), la **clarté** (phrases courtes, mots simples, répétition des mots à éviter, phrases actives, ordre logique) et la **brièveté** (supprimer les expressions creuses). **Le temps des verbes doit être respecté**. En effet, tout ce qui est expérimental et non vérifié est rédigé au passé (passé composé et imparfait) de l'indicatif, notamment les parties *Méthodologie* (*Matériels et méthodes*) et *Résultats*. Tandis que tout ce qui est admis donc vérifié est rédigé au présent de l'indicatif, notamment les parties *Introduction*, avec la citation de résultats vérifiés, *Discussion* et *Conclusion*. Toutefois, en cas de doute, rédigez au passé. Pour en savoir plus sur la méthodologie de rédaction d'un article, prière consulter le document suivant : **Assogbadjo A. E., Aïhou K., Youssao A. K. I., Fovet-Rabot C., Mensah G. A., 2011. L'écriture scientifique au Bénin.** ***Guide contextualisé de formation. Cotonou, INRAB, 60 p. ISBN : 978-99919-857-9-4 – INRAB 2011. Dépôt légal n° 5372 du 26 septembre 2011, 3ème trimestre 2011. Bibliothèque Nationale (BN) du Bénin.***

Titre

Dans le titre se retrouve l'information principale de l'article et l'objet principal de la recherche. Le titre doit contenir 6 à 10 mots (22 mots au maximum) en position forte, décrivant le contenu de l'article, assez informatifs, descriptifs, précis et concis. Un bon titre doit donner le meilleur aperçu possible de l'article en un minimum de mots. Il comporte les mots de l'index *Medicus*. Le titre est un message-réponse aux 5 W [what (quoi ?), who (qui ?), why (pourquoi ?), when (quand ?), where (où ?)] & 1 H [how (comment ?)]. Il est recommandé d'utiliser des sous-titres courts et expressifs pour subdiviser les sections longues du texte mais écrits en minuscules, sauf la première lettre et non soulignés. Toutefois, il faut éviter de multiplier les sous-titres. Le titre doit être traduit dans la seconde langue donc écrit dans les deux langues français et anglais.

Auteur et Co-auteurs

Les initiales des prénoms en majuscules séparées par des points et le nom avec 1ère lettre écrite en majuscule de tous les auteurs (auteur & co-auteurs), sont écrits sous le titre de l'article. Immédiatement, suivent les titres académiques (Pr., Dr, MSc., MPhil. et/ou Ir.), les prénoms écrits en minuscules et le nom écrit en majuscule, puis les adresses complètes (structure, BP, e-mail, Tél. et pays) de tous les auteurs. Il ne faut retenir que les noms des membres de l'équipe ayant effectivement participé au programme de recherche et à la rédaction de l'article.

Résumé

Un bref résumé dans la langue de l'article est précédé d'un résumé détaillé dans la seconde langue (français ou anglais selon le cas) et le titre sera traduit dans cette seconde langue. Le résumé est une compression en volume plus réduit de l'ensemble des idées développées dans un document, etc. Il contient l'essentiel en un seul paragraphe de 200 à 350 mots. Le résumé contient une **Introduction** (contexte, Objectif, etc.) rédigée avec 20% des mots, la **Méthodologie** (type d'étude, échantillonnage, variables et outils statistiques) rédigée avec 20% des mots, les **Résultats obtenus et leur courte discussion** (résultats importants et nouveaux pour la science), rédigée avec 50% des mots et une **Conclusion** (implications de l'étude en termes de généralisation et de perspectives de recherches) rédigée avec 10% des mots.

Mots-clés

Les 3 à 5 mots et/ou groupes de mots clés les plus descriptifs de l'article suivent chaque résumé et comportent le pays (la région), la problématique ou l'espèce étudiée, la discipline ou le domaine spécifique, la méthodologie, les résultats et les perspectives de recherche. Il est conseillé de choisir d'autres mots/groupes de mots autres que ceux contenus dans le titre.

Texte

Le texte doit être rédigé dans un langage simple et compréhensible. L'article est structuré selon la discipline scientifique et la thématique en utilisant l'un des plans suivants avec les Remerciements (si nécessaire) et Références bibliographiques : *IMReD* (Introduction, Matériel et Méthodes, Résultats, Discussion/Résultats et Discussion, Conclusion) ; *ILPIA* (Introduction, Littérature, Problème, Implication, Avenir) ; *OPERA* (Observation, Problème, Expérimentation, Résultats, Action) ; *SOSRA* (Situation, Observation, Sentiments, opinion, Réflexion, Action) ; *ESPRIT/SPRIT* [Entrée en matière (introduction), Situation du problème, Problème précis, Résolution, Information appliquée ou détaillée, Terminaison (conclusion)] ; *APPROACH* (Annonce, Problématique (permutable avec Présentation), Présentation, Réactions, Opinions, Actions, Conclusions, Horizons) ; etc.

Introduction

L'introduction c'est pour persuader le lecteur de l'importance du thème et de la justification des objectifs de recherche. Elle motive et justifie la recherche en apportant le background nécessaire, en expliquant la rationalité de l'étude et en exposant clairement l'objectif et les approches. Elle fait le point des recherches antérieures sur le sujet avec des citations et références pertinentes. Elle pose clairement la problématique avec des citations scientifiques les plus récentes et les plus pertinentes, l'hypothèse de travail, l'approche générale suivie, le principe méthodologique choisi. L'introduction annonce le(s) objectif(s) du travail ou les principaux résultats. Elle doit avoir la forme d'un entonnoir (du général au spécifique).

Matériels et méthodes

Il faut présenter si possible selon la discipline le **milieu d'étude** ou **cadre de l'étude** et indiquer le lien entre le milieu physique et le thème. **La méthodologie d'étude** permet de baliser la discussion sur les résultats en renseignant sur la validité des réponses apportées par l'étude aux questions formulées en introduction. Il faut énoncer les méthodes sans grands détails et faire un extrait des principales utilisées. L'importance est de décrire les protocoles expérimentaux et le matériel utilisé, et de préciser la taille de l'échantillon, le dispositif expérimental, les logiciels utilisés et les analyses statistiques effectuées. Il faut donner toutes les informations permettant d'évaluer, voire de répéter l'essai, les calculs et les observations. Pour le matériel, seront indiquées toutes les caractéristiques scientifiques comme le genre, l'espèce, la variété, la classe des sols, etc., ainsi que la provenance, les quantités, le mode de préparation, etc. Pour les méthodes, on indiquera le nom des dispositifs expérimentaux et des analyses statistiques si elles sont bien connues. Les techniques peu répandues ou nouvelles doivent être décrites ou bien on en précisera les références bibliographiques. Toute modification par rapport aux protocoles courants sera naturellement indiquée.

Résultats

Le texte, les tableaux et les figures doivent être complémentaires et non répétitifs. Les tableaux présenteront un ensemble de valeurs numériques, les figures illustrent une tendance et le texte met en évidence les données les plus significatives, les valeurs optimales, moyennes ou négatives, les corrélations, etc. On fera mention, si nécessaire, des sources d'erreur. La règle fondamentale ou règle cardinale du témoignage scientifique suivie dans la présentation des résultats est de donner tous les faits se rapportant à la question de recherche concordant ou non avec le point de vue du scientifique et d'indiquer les relations imprévues pouvant faire de l'article un sujet plus original que l'hypothèse initiale. Il ne faut jamais entremêler des descriptions méthodologiques ou des interprétations avec les résultats. Il faut indiquer toujours le niveau de signification statistique de tout résultat. Tous les aspects de l'interprétation doivent être présents. Pour l'interprétation des résultats il faut tirer les conclusions propres après l'analyse des résultats. Les résultats négatifs sont aussi intéressants en recherche que les résultats positifs. Il faut confirmer ou infirmer ici les hypothèses de recherches.

Discussion

C'est l'établissement d'un pont entre l'interprétation des résultats et les travaux antérieurs. C'est la recherche de biais. C'est l'intégration des nouvelles connaissances tant théoriques que pratiques dans le domaine étudié et la différence de celles déjà existantes. Il faut éviter le piège de mettre trop en évidence les travaux antérieurs par rapport aux résultats propres. Les résultats obtenus doivent être interprétés en fonction des éléments indiqués en introduction (hypothèses posées, résultats des recherches antérieures, objectifs). Il faut discuter ses propres résultats et les comparer à des résultats de la littérature scientifique. En d'autres termes c'est de faire les relations avec les travaux antérieurs. Il est nécessaire de dégager les implications théoriques et pratiques, puis d'identifier les besoins futurs de recherche. Au besoin, résultats et discussion peuvent aller de pair.

Résultats et Discussion

En optant pour **résultats et discussions** alors les deux vont de pair au fur et à mesure. Ainsi, il faut la discussion après la présentation et l'interprétation de chaque résultat. Tous les aspects de l'interprétation, du commentaire et de la discussion des résultats doivent être présents. Avec l'expérience, on y parvient assez aisément.

Conclusion

Il faut une bonne et concise conclusion étendant les implications de l'étude et/ou les suggestions. Une conclusion fait ressortir de manière précise et succincte les faits saillants et les principaux résultats de l'article sans citation bibliographique. La conclusion fait la synthèse de l'interprétation scientifique et de l'apport original dans le champ scientifique concerné. Elle fait l'état des limites et des faiblesses de l'étude (et non celles de l'instrumentation mentionnées dans la section de méthodologie). Elle suggère d'autres avenues et études permettant d'étendre les résultats ou d'avoir des applications intéressantes ou d'obtenir de meilleurs résultats.

Références bibliographiques

La norme Harvard et la norme Vancouver sont les deux normes internationales qui existent et régulièrement mises à jour. Il ne faut pas mélanger les normes de présentation des références bibliographiques. En ce qui concerne le Bulletin de la Recherche Agronomique du Bénin (BRAB), c'est la norme Harvard qui a été choisie. Les auteurs sont responsables de l'orthographe des noms cités dans les références bibliographiques. Dans le texte, les publications doivent être citées de la manière suivante : Sinsin (2020) ou Sinsin et Assogbadjo (2020) ou Sinsin *et al.* (2007). Sachez que « *et al.* » est mis pour *et alteri* qui signifie et autres. Il faut s'assurer que les références mentionnées dans le texte sont toutes reportées par ordre alphabétique dans la liste des références bibliographiques. Somme toute dans le BRAB, selon les ouvrages ou publications, les références sont présentées dans la liste des références bibliographiques de la manière suivante :

Pour les revues scientifiques :

- ✓ ***Pour un seul auteur :*** Yakubu, A., 2013: Characterisation of the local Muscovy duck in Nigeria and its potential for egg and meat production. *World's Poultry Science Journal, 69(4): 931-938. DOI: https://doi.org/10.1017/S0043933913000937*
- ✓ ***Pour deux auteurs :*** Tomasz, K., Juliusz, M. K., 2004: Comparison of physical and qualitative traits of meat of two Polish conservative flocks of ducks. Arch. Tierz., Dummerstorf, 47(4): 367-375.
- ✓ ***A partir de trois auteurs :*** Vissoh, P. V., R. C. Tossou, H. Dedehouanou, H. Guibert, O. C. Codjia, S. D. Vodouhe, E. K. Agbossou, 2012 : Perceptions et stratégies d'adaptation aux changements climatiques : le cas des communes d'Adjohoun et de Dangbo au Sud-Est Bénin. *Les Cahiers d'Outre-Mer N° 260, 479-492*.

Pour les organismes et institutions :

- ✓ FAO, 2017. L'État de la sécurité alimentaire et de la nutrition dans le monde 2017 : Renforcer la résilience pour favoriser la paix et la sécurité alimentaire. Rome, FAO. 144 p.
- ✓ INSAE (Institut National de la Statistique et de l'Analyse Economique), 2015 : Quatrième Recensement Général de la Population et de l'Habitation (RGPH-4) : Résultats définitifs. Direction des Etudes Démographiques, Institut National de la Statistique et de l'Analyse Economique, Cotonou, Bénin, 33 p.

Pour les contributions dans les livres :

- ✓ Whithon, B.A., Potts, M., 1982: Marine littoral: 515-542. *In*: Carr, N.G., Whitton, B.A., (eds), The biology of cyanobacteria. Oxford, Blackwell.
- ✓ Annerose, D., Cornaire, B., 1994 : Approche physiologique de l'adaptation à la sécheresse des espèces cultivées pour l'amélioration de la production en zones sèches: 137-150. *In* : Reyniers, F.N., Netoyo L. (eds.). Bilan hydrique agricole et sécheresse en Afrique tropicale. Ed. John Libbey Eurotext. Paris.

Pour les livres :

- ✓ Zryd, J.P., 1988: Cultures des cellules, tissus et organes végétaux. Fondements théoriques et utilisations pratiques. Presses Polytechniques Romandes, Lausanne, Suisse.
- ✓ Stuart, S.N., R.J. Adams, M.D. Jenkins, 1990: Biodiversity in sub-Saharan Africa and its islands. IUCN–The World Conservation Union, Gland, Switzerland.

Pour les communications :

- ✓ Vierada Silva, J.B., A.W. Naylor, P.J. Kramer, 1974: Some ultrastructural and enzymatic effects of water stress in cotton (*Gossypium hirsutum* L.) leaves. Proceedings of Nat. Acad. Sc. USA, 3243-3247.
- ✓ Lamachere, J.M., 1991 : Aptitude du ruissellement et de l'infiltration d'un sol sableux fin après sarclage. Actes de l'Atelier sur Soil water balance in the Sudano-Sahelian Zone. Niamey, Niger, IAHS n° 199, 109-119.

Pour les abstracts :

- ✓ Takaiwa, F., Tnifuji, S., 1979: RNA synthesis in embryo axes of germination pea seeds. Plant Cell Physiology abstracts, 1980, 4533.

Thèse ou mémoire :

- ✓ Valero, M., 1987: Système de reproduction et fonctionnement des populations chez deux espèces de légumineuses du genre *Lathyrus*. PhD. Université des Sciences et Techniques, Lille, France, 310 p.

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Pour les sites web : http:/www.iucnredlist.org, consulté le 06/07/2007 à 18 h.

Equations et formules

Les équations sont centrées, sur une seule ligne si possible. Si on s'y réfère dans le texte, un numéro d'identification est placé, entre crochets, à la fin de la ligne. Les fractions seront présentées sous la forme « 7/25 » ou « (a+b)/c ».

Unités et conversion

Seules les unités de mesure, les symboles et équations usuels du système international (SI) comme expliqués au chapitre 23 du Mémento de l'Agronome, seront acceptés.

Abréviations

Les abréviations internationales sont acceptées (OMS, DDT, etc.). Le développé des sigles des organisations devra être complet à la première citation avec le sigle en majuscule et entre parenthèses (FAO, RFA, IITA). Eviter les sigles reconnus localement et inconnus de la communauté scientifique. Citer complètement les organismes locaux.

Nomenclature de pesticides, des noms d'espèces végétales et animales

Les noms commerciaux seront écrits en lettres capitales, mais la première fois, ils doivent être suivis par le(s) nom (s) communs(s) des matières actives, tel que acceptés par « International Organization for Standardization (ISO) ». En l'absence du nom ISO, le nom chimique complet devra être donné. Dans la page de la première mention, la société d'origine peut être indiquée par une note en bas de la page, p .e. PALUDRINE (Proguanil). Les noms d'espèces animales et végétales seront indiqués en latin (genre, espèce) en italique, complètement à la première occurrence, puis en abrégé (exemple : *Oryza sativa* = *O. sativa*). Les auteurs des noms scientifiques seront cités seulement la première fois que l'on écrira ce nom scientifique dans le texte.

Tableaux, figures et illustrations

Chaque tableau (avec les colonnes rendus invisibles mais seules la première ligne et la dernière ligne sont visibles) ou figure doit avoir un titre. Les titres des tableaux seront écrits en haut de chaque tableau et ceux des figures/photographies seront écrits en bas des illustrations. Les légendes seront écrites directement sous les tableaux et autres illustrations. En ce qui concerne les illustrations (tableaux, figures et photos) seules les versions électroniques bien lisibles et claires, puis mises en extension jpeg avec haute résolution seront acceptées. Seules les illustrations dessinées à l'ordinateur et/ou scannées, puis les photographies en extension jpeg et de bonne qualité donc de haute résolution sont acceptées.

Les places des tableaux et figures dans le texte seront indiquées dans un cadre sur la marge. Les tableaux sont numérotés, appelés et commentés dans un ordre chronologique dans le texte. Ils présentent des données synthétiques. Les tableaux de données de base ne conviennent pas. Les figures doivent montrer à la lecture visuelle suffisamment d'informations compréhensibles sans recours au texte. Les figures sont en Excell, Havard, Lotus ou autre logiciel pour graphique sans grisés et sans relief. Il faudra fournir les données correspondant aux figures afin de pouvoir les reconstruire si c'est nécessaire.

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Forestry biomass potential for energy production at global scale: a systematic review

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Abstract

The feasibility of using biomass for sustainable energy production received a pivotal attention from bioenergy research. Previous research in bioenergy field resulted in a variety of trends over the past decades. Reviewing these studies holds significance in updating policymakers and enlightening the scientific community. This systematic review comprehensively assessed diverse dimensions of bioenergy, encompassing the types of forestry biomass examined, the factors influencing biomass availability for bioenergy, approaches and models used for biomass potential assessment, socioeconomic and environmental impacts, and the spatial distribution of biomass-based energy potential. Our review encompassed 56 global publications including 44 original articles and 12 secondary sources articles. The findings drawn from the systematic literature review identified crucial gaps in the field of bioenergy that ought to be addressed in future research. Previous studies in the field have paid limited consideration to forestry residues potential assessment, economic and sustainability criteria. Additionally, integrated models have received limited consideration from bioenergy research compared to resource-focused and demand-driven ones. In terms of drivers, land use change, demand for wood energy, and wood processing technology emerged as key drivers of biomass potential. Biomass use for energy was found to have a positive climate impact but a predominantly negative impact on water resources, while its impact on biodiversity appeared more neutral. With regard to bioenergy potential, America, especially Mexico exhibited the highest stand biomass potential estimated to be 60,000 PJ (Petajoules), whereas China held the highest potential of forestry residues (5,000 PJ). Based on this review, future studies are encouraged to give more consideration to forestry residues, prioritize sustainability criteria, and strive for harmonized assessments for global comparisons. Furthermore, integrating economic considerations and adopting holistic evaluations that encompass economic, social, and environmental variables are essential for the accurate assessment of forestry biomass potential.

Key words: Organic material, Potential quantification, Biomass-based energy, Comprehensive Review.

Potentiel de la biomasse forestière pour la production d'énergie à l'échelle mondiale : une revue systématique

Résumé

La faisabilité d'utiliser la biomasse en tant que ressource pour produire de l'énergie durable a reçu une attention particulière au cours des dernières décennies. La revue systématique visait à faire le point de la littérature sur l'estimation de la biomasse forestière à des fins de production d'énergie afin de fournir des informations essentielles aux décideurs politiques et à la communauté scientifique. Cette analyse a englobé 56 publications à l'échelle mondiale, couvrant un large éventail de sujets, notamment les différentes catégories de biomasse forestière, les facteurs influant sur leur disponibilité, les méthodes d'évaluation du potentiel énergétique, les impacts socio-économiques et environnementaux, ainsi que la répartition géographique du potentiel bioénergétique. Les résultats tirés de la revue bibliographique systématique mettent en lumière certaines insuffisances dans la littérature, notamment le manque d'attention portée aux résidus forestiers et aux critères de durabilité, ainsi que la sous-représentation des modèles intégrés. Parmi les principaux moteurs du potentiel bioénergétique figurent le changement d'affectation des terres, la demande de bois-énergie et les avancées technologiques liées. L'utilisation de la biomasse présente des avantages en termes de climat, bien que des effets négatifs sur les ressources en eau soient observés, avec un impact positif sur la biodiversité. Sur le plan géographique, l'Amérique, en particulier le Mexique, se distingue par son potentiel élevé en biomasse de peuplement estimé à 60.000 PJ (Pétajoules), tandis que la Chine affiche un potentiel important (5.000 PJ) en ce qui concerne les résidus forestiers. Les chercheurs sont vivement encouragés à accorder une attention plus soutenue aux résidus forestiers, à mettre en avant la durabilité et à uniformiser les méthodologies d'évaluation afin de favoriser des comparaisons au niveau global. De surcroît, il est impératif d'intégrer des considérations économiques et d'adopter des méthodes d’évaluation holistiques prenant en compte des variables économiques, sociales et environnementales pour une évaluation précise du potentiel de la biomasse forestière.

Mots clés: Biomasse, Quantification, Energie biomassique, Revue systématique.

Introduction

Transition toward renewable energy sources (RESs) stands as one of the ideal alternatives to combat the global environmental and climate crises. Among the various RESs, biomass is anticipated to maintain its pivotal role in meeting the escalating global energy demands. The transition towards renewable energy is critical to meet the unstoppable growing energy requirements (Pintér *et al.*, 2022), but also in response to the increasingly urgent imperative for energy self-sufficiency. Moreover, the multifaceted issue of biomass potential and utilization holds paramount significance not only for sustaining energy needs but also for ensuring the food and feed supply, an imperative highlighted within the United Nations (UN) Sustainable Development Goals (SDGs). Various studies have provided valuable insights into the potential of biomass from small scale (village, town, country) to regional to the global scale (Van Holsbeeck *et al.*, 2020 ; Kovalyshyn *et al.*, 2019 ; Pokharel *et al.*, 2019 ; Thrän *et al.*, 2010). Numerous studies have examined the social and economic feasibility of biomass use for energy by specifically investigating people intention, attitude and willingness to support biomass-based energy projects (Wüste and Schmuck, 2013; Gao *et al.*, 2019 ; Wegener and Kelly, 2008 ; Minas *et al.*, 2020). While some studies have addressed the quantitative potential of biomass for energy purposes, others have discussed the implementation feasibility and the environmental, economic and social impacts (Errera *et al.*, 2023; Wang *et al.*, 2018).

Reviewing these studies can be helpful in making informed decisions regarding energy planning and policy development. In the context of energy transition, it allows policymakers and energy experts to gauge how much biomass can contribute to achieving renewable energy targets. A review of these studies in this field can identify gaps in knowledge, highlight areas where further research is needed, and contribute to a more comprehensive understanding of biomass potential and its implications. Among biomass resources, pivotal attention has been paid to forestry biomass over the past decades (Sertolli *et al.*, 2022). Forestry biomass encompasses stemwood, primary forestry residues, secondary forestry residues, short-rotation plantations woody biomass, and trees outside of forests (Vis, 2010). It was reported that forestry biomass especially forestry residues are a promising alternative to slow down environmental impacts and the cost of biofuel production instead of crop feedstocks (Lin and Lu, 2021). Primary forestry residues comprise logging residues, and stumps resulting from forest operations. Secondary forestry residues comprise by-products of the forest industries, which cover a spectrum of materials such as sawdust and cutter chips, bark, slabs, lump wood residues, and black liquor (Thiffault *et al.*, 2014). Forestry residues are projected to play a major role in the future contribution of bioenergy to the global energy demand.

The current global potential of residues biomass (from crops and forests) that could sustainably be used for energy was estimated to be 50 EJ (Exajoules) yr-1 and about 26% of this potential is shared by forestry residues (Gregg and Smith, 2010). The global future bioenergy potential of residues is projected to be 100 EJ yr-1 by 2050 of which 20% will probably be shared by forestry residues (Gregg and Smith, 2010). The use of forestry residues for bioenergy production is challenged by a number of social, economic, environmental, and political factors that limit its availability, despite its significant role in the current and future energy portfolio. Additionally, different types of biomass potential were assessed across space and over time using various methodological frameworks in the literature. Reviewing these factors is imperative to inform scientists in the field and policymakers for accurate assessments and decision-making in the future. In theory, there are five types of potential (theoretical, technical, economic, implementation, and sustainable) that are commonly assessed in the literature (Voivontas *et al.*, 2001). The theoretical biomass potential, which represents the maximum annual yield of forest biomass per unit of area, considering all possible restrictions, including alternative biomass uses and efficiency at the collection level (Voivontas *et al.*, 2001). According to IRENA (2013), this potential can be expressed as the total maximum volume of residues that could be produced theoretically for bioenergy production within basic biophysical limits and within a specific timeframe. The technical potential concept refers to the part of the theoretical potential that can be harnessed within the confines of existing technological capacities and under the specific techno-structural framework conditions (Batidzirai *et al.*, 2016). The economic potential represents the fraction of the technical potential that satisfies economic criteria (Papilo *et al.*, 2017; Tkachenko and Golovko, 2020). This refers to the portion of energy distributed relative to competing energy sources. It takes into account energy production costs, facility capacity, and the profitability of the proposed investment. It may include cost estimates for the entire supply chain to determine economic feasibility at a distribution level. The implementation potential refers to the subset of the economic potential that can be effectively put into practice within a given timeframe. It assessment considers a range of socio-political framework conditions, including economic, institutional, and social constraints, along with policy incentives (Papilo *et al.*, 2017; Thrän *et al.*, 2010). This concept also encompasses the evaluation of the social, economic, and environmental impacts of bioenergy. The concept of sustainable potential refers to the result of incorporating social, economic, and environmental, economic, and social sustainability criteria in biomass resource assessment.

The sustainable potential is also known as the surplus of biomass, which is the unused portion of the produced biomass after accounting for sustainability criteria (Vis, 2010). Various types of potential have been discussed in the literature, incorporating different criteria. One such concept is the "available potential," introduced to assess the quantity of biomass that can be economically and technically harvested and transported for energy purposes prior to conversion. This assessment takes into account limitations related to harvest machinery, truck size, and transport distance. Another concept, the "technological biomass potential," has received limited attention in the literature. It pertains to the energy that can be generated using specific conversion technology, while considering factors such as the capacity of the conversion facility and its efficiency. This concept is particularly relevant for identifying potential power facilities when factors like available biomass, facility capacity, technology, and transport distance are known (Naqvi *et al.*, 2018). Furthermore, some authors have introduced the term "environmental biomass potential," operating at a similar level of analysis as the economic biomass potential. However, it focuses on environmental aspects related to bioenergy production. This concept encompasses emissions during energy production and non-biogenic emissions resulting from machinery use, which impact the carbon neutrality of the bioenergy system. Similar to the economic perspective, it evaluates bioenergy in comparison to reference or fossil energy systems (Van Holsbeeck *et al.*, 2020).

Studies on forestry biomass potential are numerous and dynamic. Several authors have published about the topic across the globe from local to the global scale using either bibliometric analysis or systematic review (Alizadeh *et al.*, 2020; Qazi *et al.*, 2019; Adedayo *et al.*, 2021; Afrane *et al.*, 2022; Sertolli *et al.*, 2022). While bibliometric reviews are an alternative, systematic reviews are generally favored due to their multiple advantages such as concise and comprehensive summary of the existing evidence related to a specific topic, gaps identification, and methodological advancement. In this study, we reviewed key findings on biomass potential for bioenergy using a rigorous systematic review. Specifically, the review focuses on the types of forestry biomass and potential assessed, factors driving biomass availability for bioenergy, biomass potential assessment approach and models, socioeconomic and environmental related impacts, and spatial distribution of biomass-based energy potential.

General Methodological Framework of the Review

In this study, we have first conducted a bibliometric search in Scopus using a Boolean equation that encompasses various search terms related to the topic. Review articles were included in the search as secondary sources given that they could not be used in the data extraction process during the systematic review. Then, after the bibliometric search, the database of the original articles was submitted to the systematic review which has been conducted in three phases: study selection based on inclusion and exclusion criteria, study analysis, and discussion of key results and conclusions. The study analysis involved verifying whether the study fell within the scope of this review's subject and assessing the adequacy of the methods used, including the time frame, potential types, spatial coverage, and biomass types. Finally, we have discussed the sources of variation in the results and provided conclusions and recommendations. In Figure 1 is summarized the general methodological framework for the review.

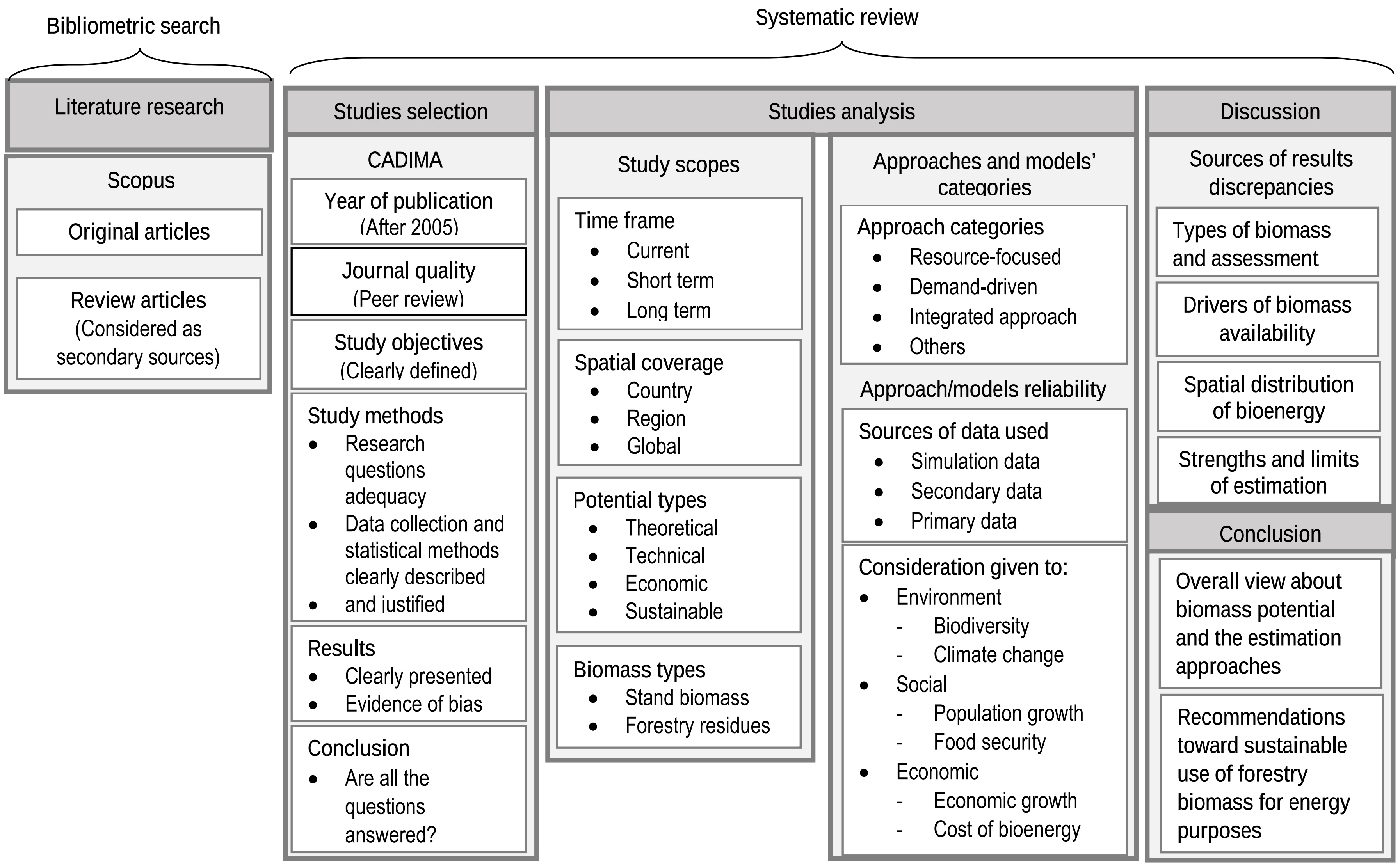

Figure 1. Summary of the general methodological framework used for the review

We have conducted a literature search in December 2022 in the Scopus database (https://www.scopus.com/home.uri), covering scientific publications from 1987 to 2022. The Scopus database was preferred because it encompasses a wide range of scientific documents. The year 1987 has been used as the start year because bioenergy-related studies and debates emerged from this year (Clark, 2018). A refined literature search, considering original articles and review articles, has been performed in Scopus based on the following broad search terms:

"Biomass availability" OR "Biomass assessment" AND "Bioenergy" AND [LIMIT-TO (PUBSTAGE, "final")] AND [LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")] AND [LIMIT-TO (EXACTKEYWORD, "Biomass") OR LIMIT-TO (EXACTKEYWORD, "Bioenergy") OR LIMIT-TO (EXACTKEYWORD, "Forestry") OR LIMIT-TO (EXACTKEYWORD, "Biomass Availability") OR LIMIT-TO (EXACTKEYWORD, "Agricultural Wastes") OR LIMIT-TO (EXACTKEYWORD, "Aboveground Biomass") OR LIMIT-TO (EXACTKEYWORD, "Crop Residue") OR LIMIT-TO (EXACTKEYWORD, "Forest Biomass") OR LIMIT-TO (EXACTKEYWORD, "Woody Biomass") OR LIMIT-TO (EXACTKEYWORD, "Biomass Resources") OR LIMIT-TO (EXACTKEYWORD, "Above Ground Biomass") OR LIMIT-TO (EXACTKEYWORD, "Estimation Method") OR LIMIT-TO (EXACTKEYWORD, "Fuelwood") OR LIMIT-TO (EXACTKEYWORD, "Municipal Solid Waste") OR LIMIT-TO (EXACTKEYWORD, "Modeling") OR LIMIT-TO (EXACTKEYWORD, "Agricultural Residues") OR LIMIT-TO (EXACTKEYWORD, "Logging Residues") OR LIMIT-TO (EXACTKEYWORD, "Biomass Potential")].

Based on this Boolean equation, a total of 1,333 publications comprising 1,138 original articles and 195 review articles have been downloaded. However, we considered only original articles for the systematic review. Review articles were used as secondary database. We have employed a rigorous systematic review methodology, adhering to established guidelines (Liu *et al.*, 2023). The review has been conducted by first formulating research questions aligned with our research objectives. Furthermore, we established the search strategy, search strings, and criteria for inclusion and exclusion as summarized below. The review has been planned by proposing the research questions relevant to our research objective. Further, we defined the search strategy, search strings and inclusion/exclusion criteria.

1. Formulation of research questions: Our first step involved the precise definition of research questions to delineate the study scope effectively. These questions served as a compass, guiding our exploration of the existing literature. The following research questions were defined to achieve the research objectives.

    i. What types of forestry biomass and assessment potential have been most frequently assessed in the field of bioenergy?

       The aim of this question was to inform policymakers about the type of biomass that can sustainably be valorized for energy production but also the type of assessment potential. This can provide insights into the sustainability and environmental implications of bioenergy production. It helps allocate resources effectively in research and development by guiding investments and efforts toward the most promising sources.

    ii. What has been the key drivers of forestry biomass availability for bioenergy?

       The aim of this question was informing policymakers about social, economic, environmental and technological factors that can hinder the feasibility of harvesting forestry biomass for energy purposes. Understanding these drivers can help forest managers and policymakers make informed decisions about sustainable forestry practices. It can also help them to optimize the supply chain for bioenergy production.

    iii. What are the sustainability criteria addressed?

       Sustainable criteria are required when the research aims to assess the sustainable or implementation potential of biomass. Identifying the most discussed criteria in the literature is informative and will encourage the use of integrated models for bioenergy sustainably.

    iv. What are the spatial locations with high bioenergy potential around the globe?

       This question was defined to provide insights into the spatial distribution of biomass potential around the world. This can help policymakers plan and prioritize their energy strategies and climate action efforts.

v. What has been the most employed assessment approaches and methods and their limits?

The relevance of this question was to identify the most accurate methods for forestry biomass assessment, the reasons for their choice and their limits. This is important in designing sustainable planning of management of forests. It can additionally be used to improve the efficiency of the biomass supply chain.

2. Systematic Keyword Search: To comprehensively retrieve relevant studies, we have conducted a systematic keyword search in Scopus using the same broad search string used in the bibliometric search.
3. Inclusion and exclusion criteria: To select the appropriate studies for inclusion in the review, the metadata and the abstracts of the papers were reviewed, and the following inclusion criteria were applied. Selected papers were I1: peer-reviewed, I2: published between 2005 and 2022, I3: this is an original or review article, I4: should necessarily discuss the search terms "forestry" OR "forest" AND "biomass" OR "residue" AND "bioenergy" AND "potential" and "environment" OR "biodiversity". Publications that did not meet the inclusion criteria were excluded from the study. We have applied the exclusion criteria E1-E3 to filter out irrelevant publications. E1: publications not focusing explicitly on forestry biomass potential for bioenergy; E2: publications that do not discuss the environmental impact of using forestry biomass for bioenergy production, E3: publications do not discuss about factors affecting forest biomass availability for bioenergy.

Findings drawn from the systematic literature review

In this section, we present the findings of our search and extraction of information from relevant sources and databases.

Article search and selection

The initial search returned 1,333 papers, as depicted in Figure 2. Then, we have meticulously applied the inclusion criteria (I1, I2, I3, and I4) described earlier to select articles for inclusion. A researcher conducted a detailed examination of article titles and abstracts, resulting in the selection of 170 studies. Subsequently, in the second stage, a second researcher (one of the co-authors) and an experienced, independent researcher assessed the preselected studies using the exclusion criteria (E1, E2, and E3). Whenever discrepancies or agreements emerged in their assessments, the researchers convened face-to-face meetings to review and achieve consensus. In cases where a consensus remained elusive, all three researchers collectively reviewed the paper and applied the predefined exclusion criteria for study exclusion. In the end, we identified 56 papers including 44 from the systematic selection and 12 as secondary sources for the review.

Data Extraction and Analysis

Following the guidelines outlined in Kitchenham (2004), we have conducted a systematic data extraction process to discern pertinent information from the selected pool of 56 studies. This meticulous data extraction procedure comprised the subsequent steps: Initially, Zotero reference manager has been used to construct a well-organized database of publications. Within this database, we have meticulously logged essential details concerning the concepts, contributions, and findings from each of the 56 studies into a spreadsheet. From each publication, we extracted the following data:

- Review date: The date of the review.
- Publication details: Including the title, authors, and references.
- Database source: The origin of the publication within a specific database.
- Year of publication: The year in which the publication was released.
- Assessment time frame: Indicating whether the assessment pertained to the current or future (short-term or long-term) evaluation of forestry biomass.
- Spatial coverage: Referring to the geographical scope, whether at the country, regional, or global level.
- Type of biomass assessed: Identifying whether the assessment focused on stand biomass or residues (primary or secondary).

- Assessment potential: Encompassing the theoretical, technical, economic, implementation, and sustainable potential of biomass.
- Assessment methods: Describing the methodologies utilized in appraising biomass potential.
- Data sources: Categorizing data sources as primary, secondary, or simulation data.
- Sustainability consideration: Addressing social, economic, and environmental dimensions related to sustainability.
- Environmental impact: Evaluating the positive or negative effects on the environment.
- Environmental components: Encompassing climate, soil, water, and biodiversity.
- Biodiversity components: Specifically focusing on soil, water, and vegetation.
- Impact on biodiversity: Analysing the positive or negative influence of bioenergy-based forest biomass on each of these components.
- Biomass potential: Signifying the total bioenergy value reported in the studies.

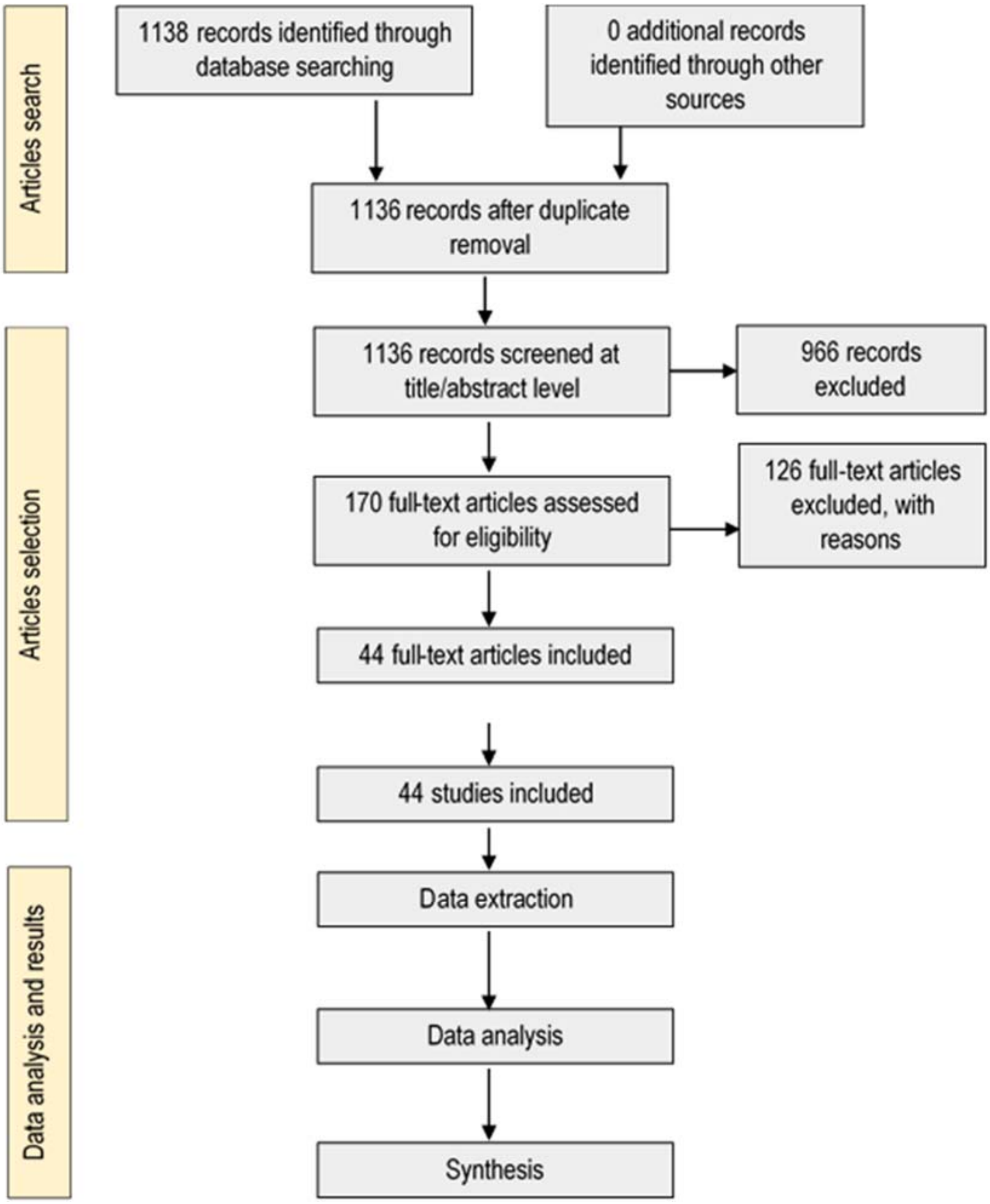

Figure 2. The flow diagram of the systematic review

Quality of Publications

The quality of study was assessed based on similar criteria that have been previously employed in other systematic reviews (Inayat *et al.*, 2015). These criteria included four key aspects which were assessed by a well-known independent researcher. When a criterion is met, the researcher gives the grades 1 and 0 when it is not. The four criteria used to assess the studies quality are described below:

- Criterion 1 (C1): Determining whether the aims, objectives, measured variables and research questions were clearly defined and were adequate.
- Criterion 2 (C2): Evaluating whether the research methods including data collection and statistical analyses were clearly described and justified.
- Criterion 3 (C3): Assessing whether the research outcomes were sufficient for our research purposes.
- Criterion 4 (C4): Verifying whether the research questions were addressed and the study limits were discussed.

Analysis and results presentation

Following data collection, we analysed and presented our findings in detail, employing descriptive statistics. The insights gained from this analysis played a pivotal role in shaping the conclusions of our study.

Overview of Selected Studies

A total of 56 studies were reviewed including 44 original articles and 12 review articles as secondary sources (Figure 3.A; Appendix. A1). All the reviewed studies met the criteria for quality and received high grades, as indicated in Figure 3.C, with scores ranging from 80% to an impressive 92%. In terms of spatial coverage, the preponderance of the studies originated from Europe (42.85%) and North America (41.07%), as shown in Figure 3.B. Conversely, scientific production in Asia (5.35%), Australia (5.35%), and Africa (3.57%) was notably limited. We found two studies that were conducted in Africa.

The first was the one of Kemausuor *et al.* (2014) in Ghana on biomass residues availability for bioenergy. The second was a regional-scale study on the future of residues-based bioenergy for industrial use in Sub-Saharan Africa conducted by Röder *et al.* (2022). Only a marginal percentage (1.78%) of studies adopted a global perspective. The only study that covered the global scale was the one of Smeets and Faaij (2007) on the drivers of bioenergy potential from forestry biomass by 2050. A trend analysis of scientific production, as presented in Figure 3.D, revealed two distinct periods of pronounced growth in the number of publications addressing forestry biomass potential for bioenergy. The first period, spanning from 2008 to 2014, witnessed a marked upsurge in research output. Subsequently, another phase of heightened research activity occurred between 2019 and 2022. It is noteworthy that research on this subject experienced a relative decline in attention between 2014 and 2019, as indicated by a decrease in the number of publications.

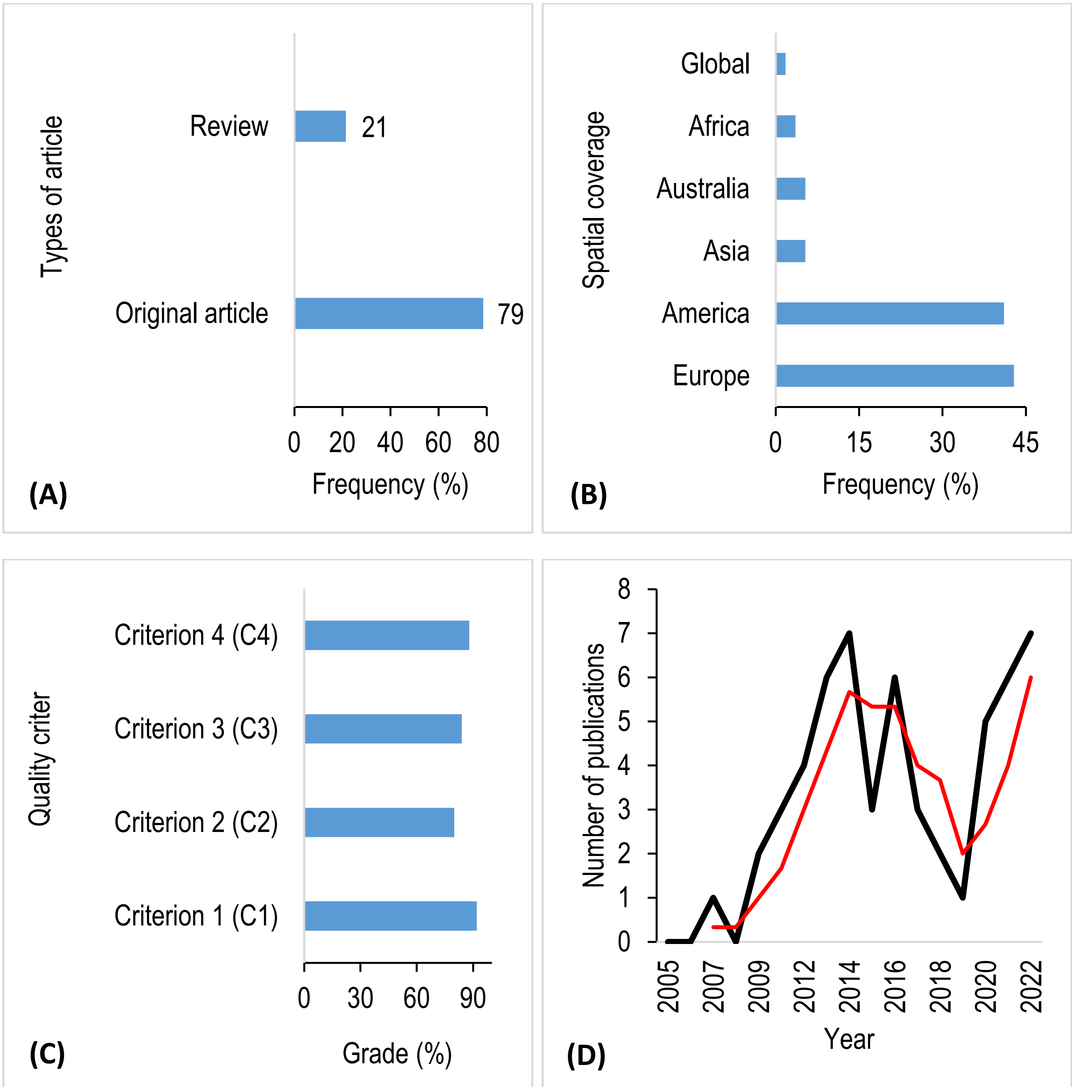

Figure 3. Overview pattern of (A) types of publication, (B) Spatial coverage of studies, (C) Quality of studies and (D) Trend in scientific production over a year (from 2005 to 2022)

C1=Adequacy of the study aim, objectives, variables and research questions; C2=Details and justification of research methods including data collection and statistical analyses; C3=Convergence between the study outcomes and our research purposes; C4=Response to the research questions and discussion about the study limits.

What types of forestry biomass and assessment potential have been the most assessed?

Three types of biomass have been assessed across the reviewed studies (Figure 4.A). These included stand biomass assessed by 44.64% of the reviewed studies followed by primary forestry residues (33.92%) and secondary forestry residues (23.21%). The reviewed studies have assessed four types of potential, including the theoretical, technical, implementation, sustainable and economic potential (Figure 4.B). The theoretical potential stands as the most assessed type (53.57%) followed by the technical potential (25%). Studies have paid marginal credit to the sustainable (5.36%) and economic potential (3.57%).

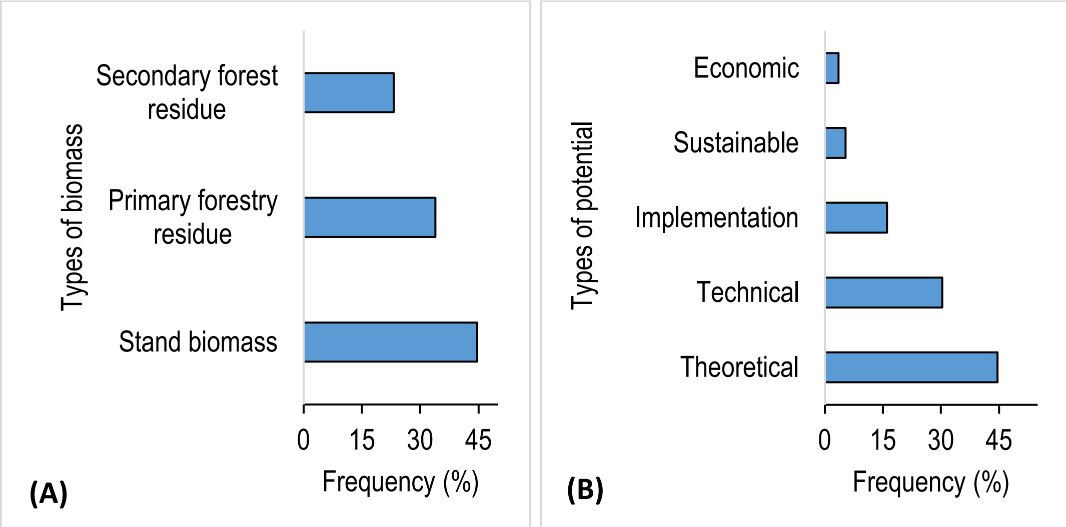

Figure 4. Frequency distribution of studies by (A) types of biomass assessed and (B) types of potential assessed

What has been the key drivers of forestry biomass availability for bioenergy?

The reviewed publications have discussed various drivers that have the potential to influence forestry biomass availability for bioenergy. We identified 16 key drivers (Table 1) among which land use change (17.86%), demand for wood energy (10.71%), wood processing technology (10.71%), plantation installation (8.93%) and people's willingness to accept renewables (8.93%) were the most quoted.

Table 1. Drivers of forestry biomass availability for bioenergy according to the type of potential

Drivers	Types of potential					Citation frequency of drivers (%)
	Theoretical	Technical	Sustainable	Implementation	Economic	
Land use change	x	x		x		17.86
Future demand for wood energy	x	x	x			10.71
Processing plant technology		x				10.71
Plantation establishment rates	x	x	x			8.93
Social acceptance			x			8.93
Fragmentation	x	x				7.14
Supply of wood from forests	x	x	x			5.36
Cost of biomass			x		x	5.36
Climate policy	x	x				3.57
Forest type	x	x				3.57
Geographical location		x		x		3.57
Wood biomass demand		x			x	3.57
Residues management options	x				x	3.57
Properties of the wood	x	x				3.57
Harvest types of merchantable timber	x					1.79
Size of processing industries	x					1.79
Total						100

When we linked the drivers to the types of biomass potential, we have found 11 out of the initial 16 drivers that potentially affect the theoretical and technical potential, as summarized in Table 2 (see *infra: What has been the most used assessment approaches and models?*). Five, two, and three drivers were noted to have an impact on the sustainable, implementation, and economic potential, respectively. The theoretical and technical potential primarily appear to be driven by factors such as climate policy, forest type, future wood energy demand, land fragmentation, land use changes, plantation establishment rates, wood supply from forests, and wood properties. Sustainable potential, on the other hand, is influenced by future wood energy demand, plantation establishment rates, wood supply from forests, the willingness of individuals to contribute biomass, and the cost associated with biomass production. Factors that drive the implementation potential are the geographical location of bioenergy facilities and land use changes. Meanwhile, wood biomass demand, residues management options, and biomass cost were identified as the key drivers of the economic potential. As presented in the table 1, certain drivers were found to be specific to particular potential types. For instance, wood biomass demand and processing plant technology were unique to the technical potential, while wood biomass demand and processing plant technology were specific to the theoretical potential. The willingness of individuals to support bioenergy was specific to the sustainable potential. Notably, no specific driver was identified for the implementation and economic potential.

What was the key sustainability criteria accounted for and the environmental impacts addressed?

The reviewed studies considered three sustainability criteria when assessing forestry biomass potential for bioenergy, as illustrated in Figure 5.

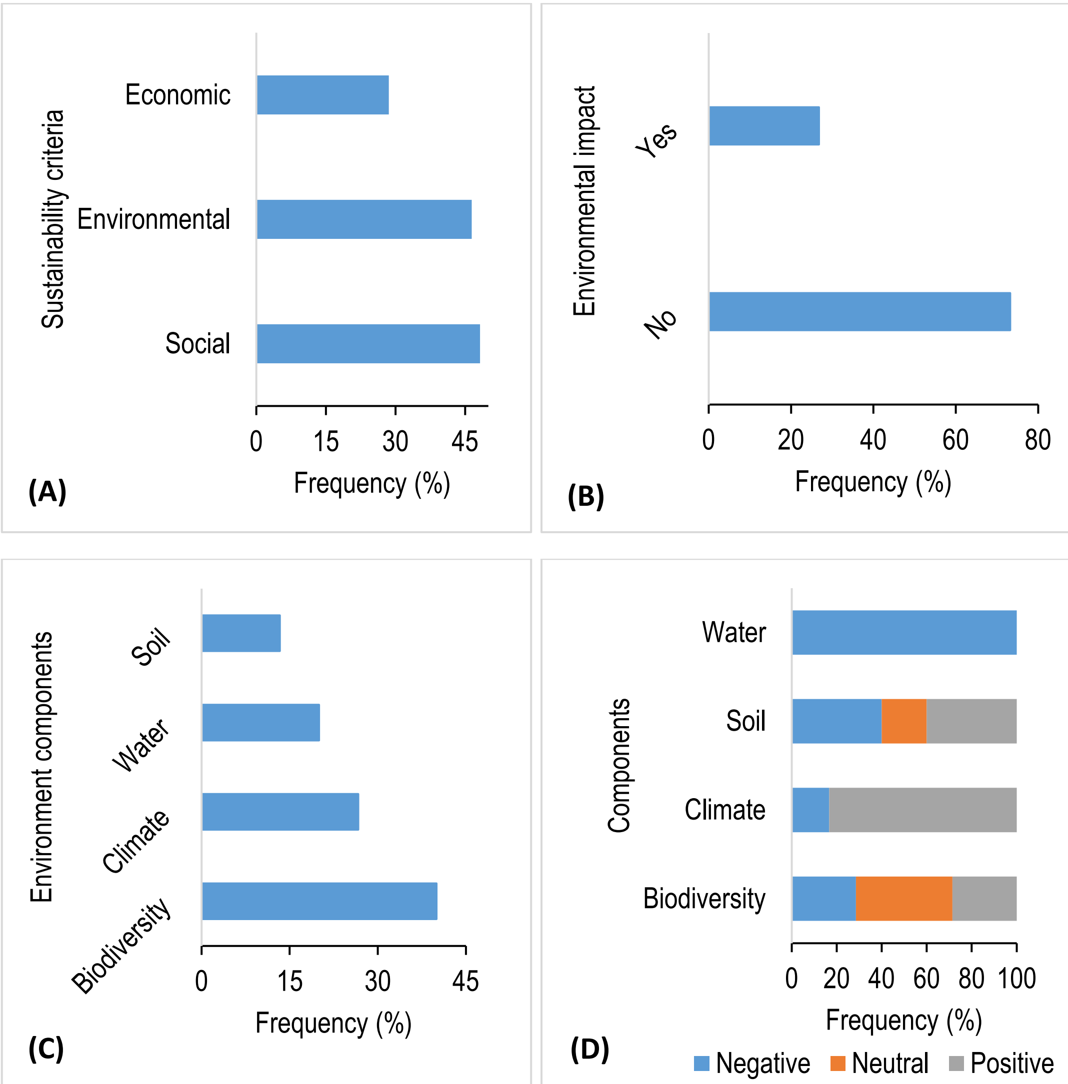

Figure 5. Percentage of studies that discussed (A) the sustainability criteria related to the use of forestry biomass for bioenergy production (B) the positive, negative or neural impact on environment components (C) the environment components influenced (D) the use impact or not on environment

The most frequently considered criteria were social constraints (48.21%) and environmental constraints (46.42%) (Figure 5.A). Economic criteria received comparatively less attention from the studies (28.57%). Regarding the environmental impacts, a minority of studies (26.79%) indicated that the use of forestry biomass for bioenergy production would have a substantial impact on the environment, while the majority (73.21%) concluded that it would have a neutral effect (Figure 5.B). Among the environmental components, biodiversity (40%) has been the most commonly mentioned as being affected by bioenergy production from forestry biomass, followed by climate (26.67%) and water (20%) (Figure 5.C). Soil impact was raised by only 13.33% of the reviewed studies. Concerning the reported impact, climate (83.33%) has been most frequently reported as positively influenced by bioenergy production from forestry biomass (Figure 5.D). Only 16.67% of the reviewed studies reported a negative impact on climate. None of the studies reported a negative impact on the economy, but some studies (11.11%) reported a neutral impact. Regarding biodiversity, the majority of studies (42.86%) reported a neutral impact, while a minority reported negative (28.57%) and positive (28.57%) impacts. All the studies reported a negative impact on water, and concerning soil, a majority (40%) reported either a positive or negative impact, with the minority reporting a neutral impact.

What are the spatial locations with high bioenergy potential around the globe?

The highest bioenergy potential derived from stand biomass has been observed in Mexico, with a theoretical potential of 60,220 PJ of energy (Figure 6.A). Following Mexico, the Netherlands ranked second with 10,764 PJ. However, it's worth noting that Mexico was among the countries with a limited supply of bioenergy from available forestry residues (Figure 6.B). Conversely, China leads globally in terms of the supply of bioenergy from forestry residues, with 4,701 PJ, followed by the USA with 308 PJ (Figure 8.B). Among the reviewed studies, Ghana was the only African country identified, and it was found to have the capacity to supply 0.67 PJ of bioenergy from forestry residues.

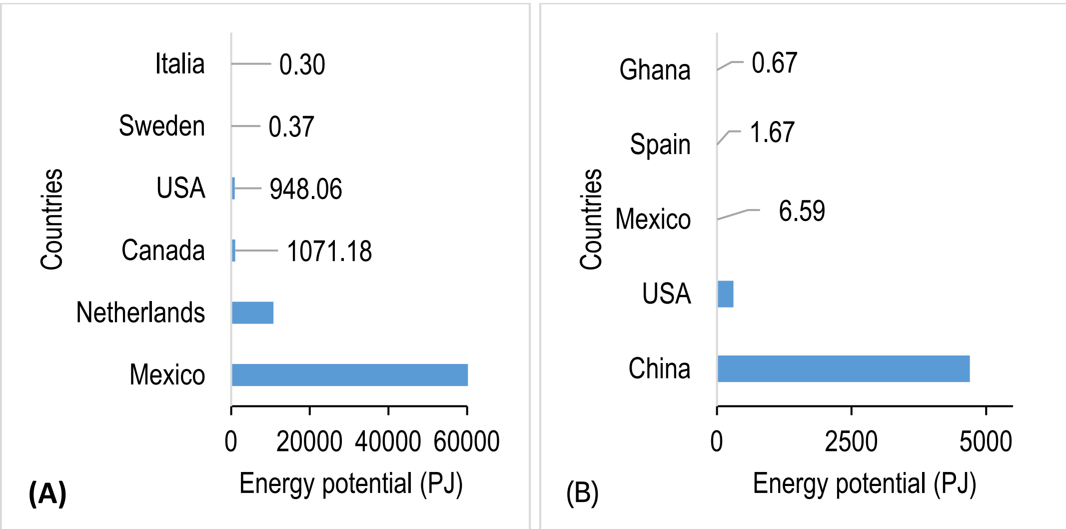

Figure 6. Spatial distribution of bioenergy potential from (A) forest stand biomass and (B) forestry residues. Only the world countries covered by the assessments were displayed

what has been the most used assessment approaches and models?

The resources-focused approach has been the most commonly employed methodological framework in the 56 reviewed studies, followed by the demand-driven approach. Here, 71.43% of the reviewed studies used the resources-focused approach, while 26.79% employed the demand-driven approach (Table 2). In contrast, the integrated approach was limitedly used, with only 1.78% of the studies incorporating it into their methodology. We identified 15 estimation models, of which 8 were employed for the resources-focused assessment. These include allometric equations, Biomass Inventory and Mapping Assessment Tool (BIMAT), Carbon Budget Model (CBM-CFS3), Biomass Opportunity Supply Model (BiOS), Geographic Information System (GIS), Statistical-Focused analysis (SF), Life Cycle Assessment (LCA), and Climate-Sensitive Process-Based Modelling (PBM). Besides, some studies have combined different estimation models, such as GIS+SF and SF+MCA. For the demand-driven approach, studies employed five models, including Statistical Focused (SF), Global Change Assessment Model (GCAM), Cost-Supply Analysis (CSA), Cost Minimizing Linear Programming Model (CMLPM), and Logistic (logit) model. Some studies also combined SF with GCAM and SF with CSA for the demand-driven approach.

We found two integrated models: Scenario Modelling Analysis (SMA) and Multicriteria Analysis (MCA) which account for a wide range of sustainability criteria to provide a holistic assessment of biomass potential for bioenergy.

Table 2. Forestry biomass estimation approaches and models developed by the 56 reviewed studies

Models	Approach used		
	Demand-driven (26.79%)	Integrated approach (1.78%)	Resources-focused (71.43%)
Allometry			x
BIMAT			x
CBM-CFS3			x
BiOS			x
CMLPM	x		
GIS			x
GIS+SF			x
LCA			x
Logistic (logit)	x		
PBM			x
SF			x
SF+CSA	x		
SF+GCAM	x		
SF+MCA		x	x
SMA		x	

Analysis

In the study, we conducted a comprehensive review of biomass potential for bioenergy over 35 years (1987-2022). The review encompasses various aspects, including types of forestry biomass assessed, biomass potential types, factors driving biomass availability for bioenergy, assessment methods, environmental sustainability concerns, and the spatial distribution of biomass-based energy potential. We found that stand biomass was the most assessed type of biomass, while forestry residues have received limited attention in bioenergy research. Previous reviews have also reported a similar finding (Titus *et al.*, 2021). The focus on stand biomass can be attributed to its greater availability and accessibility. In many regions, there is often a larger and more readily available supply of stand biomass compared to forest residues. Forestry residues, such as dead trees, branches, tops, and logging residues, are often less accessible and may require additional effort and cost for collection and processing. Another reason is the economic viability. Stand biomass is often considered more economically viable for biomass harvesting and bioenergy production because it contains a significant amount of energy and can be harvested with existing forestry practices. The underrepresentation of forestry residues in previous studies is a research gap in the field that should be addressed in future research. Forest residues can be a feasible alternative for converting energy into fuels, electricity, or heat, and their energy balance is close to zero (Nurek *et al.*, 2019 ; Yemshanov *et al.*, 2018).

Our results revealed that assessments of biomass potential tend to prioritize theoretical and technical potential rather than the economic, sustainable, and implementation potential, indicating that more emphasis is placed on production capacity rather than immediate economic or environmental considerations (Ferdous *et al.*, 2023). These results are consistent with previous studies that also highlight the importance of stand biomass in tree growth and forest regeneration (Ferdous *et al.*, 2023; Zoma and Sawadogo, 2023). However, it is important to note that these results may vary depending on geographic regions and local specificities (Titus *et al.*, 2021). The relative underrepresentation of economic and environmental considerations in biomass potential assessment raises questions about the balance between technical efficiency and the broader implications of sustainability and environmental impact (Crawford *et al.*, 2016). Additionally, this underrepresentation suggests future studies should more prioritize sustainability criteria in biomass potential assessment. The particular emphasis placed on theoretical and technical aspects underlines the predominance of research in the development of innovative technologies. However, it is becoming clear that the practical realization of these advances requires broader consideration. With this in mind, our review identified land use change, future demand for wood energy, and wood processing plant technology as the major drivers of biomass potential, especially the theoretical and technical (Aizooky and Hannhart, 2019). Other drivers such as climate policy, biomass cost, social acceptance of bioenergy, etc. were also discussed by previous studies. All these driving factors may play an important role in determining forest biomass potential, highlighting the need for a comprehensive assessment that goes beyond technical aspects such as stand age, species composition, altitude, valley depth, slope and exposure. In similarity to our review, previous reviews have also identified these factors to be the potential drivers of biomass potential at the global, regional and local scales (Breunig *et al.*, 2018; Cadham, 2015; Ross *et al.*, 2021; Smeets and Faaij, 2007).

The influence of land use change as a major driver implies that alterations in land use, such as converting forest areas into agricultural land or urban development, can impact the availability of biomass resources. These changes may affect the quantity and quality of biomass resources for bioenergy, with potential consequences for sustainability and environmental impact. The identification of future demand for wood energy as a major driver highlights the importance of considering market and consumption trends in bioenergy planning. This suggests that the projection of increased demand for wood-based bioenergy is a driving force behind assessing biomass potential. Such demands can be influenced by factors like energy policies, climate goals, and shifts in consumers' preferences. The role of wood processing plant technology in influencing biomass potential underscores the significance of technological advancements and innovations in biomass use. It may imply that improvements in processing methods can increase the efficiency and viability of using woody biomass for bioenergy production. This can include advancements in conversion technologies and equipment.

A salient aspect of our findings is the growing recognition of the impact of social, climatic and economic aspects on forest biomass potential. This shift towards a holistic approach transcends the traditional perspective focused on technical performance, signaling an awareness of the importance of broader dimensions to ensure the lasting success of initiatives (Clifton-Brown *et al.*, 2023; Wu *et al.*, 2022). Studies have demonstrated the additional environmental benefits of using perennial biomass crops (PBC) as feedstock for the bioeconomy, but their deployment has stagnated due to social, economic and political uncertainties (Hajjar *et al.*, 2020). Community forest management initiatives have often yielded positive environmental and income outcomes, but forest access and resources rights have been negatively affected by policies to formalize community forest management (Daigneault and Favero, 2021). The future of the global timber market and forest area is strongly influenced by socio-economic and technological factors, with large variations in estimates under different scenarios (Agyemang *et al.*, 2021).

Our review highlights the underconsideration of the economic dimension among evaluated sustainability criteria in the literature. This gap has previously been raised by Liu *et al.* (2023) who observed the frequent underestimation of economic potential in the scientific literature. Our results call for a thorough financial assessment, thus highlighting the crucial importance of taking into account economic considerations for a comprehensive assessment of forest biomass potential. The specificity of the factors depending on the type of potential emerges as an essential consideration. Sustainability criteria that were more considered in the literature include social and environmental constraints (Aizooky and Hannhart, 2019). This is because the social and environmental dimensions are the most considered with regard to sustainable development goals (Zakari *et al.*, 2022). Policymakers and researchers may therefore prioritize studies that investigate how bioenergy practices affect living people, ecosystems, carbon emissions, air and water quality, and biodiversity. In terms of environmental impacts, the majority of studies conclude that climate positively benefits from the using forest biomass for bioenergy production while the impact on water resources are assessed to be more negative. The impact on biodiversity was assessed to be more neutral. Comparing these results with other similar studies may highlight trends and discrepancies, such as variations in the consideration of sustainability criteria and impact assessment methods (Brandão *et al.*, 2015). The impact of bioenergy development on biodiversity may also depend on the biodiversity variable considered. For example, Castano-Villa *et al.* (2019) found biomass conversion into energy had a neutral impact on species richness whereas the impact was positive on species abundance.

Regarding the methods for assessing biomass potential, previous studies predominantly favoured resource-based models over demand-driven and integrated models. This preference is somewhat surprising because integrated models, which combine demand-driven and resource-focused approaches, are generally expected to offer more accurate insights for policymakers (Faaij, 2018). This bias might stem from the possibility that our reviewed database might have overlooked studies utilizing integrated assessment models. Additionally, the emphasis on available resources in different regions could contribute to this trend.

Within the reviewed articles, we identified only two integrated models: scenario modelling analysis and multicriteria analysis. Notably, the Bioenergy Scenario Model (BSM) stands out as a frequently employed scenario-based model. BSM is a meticulously validated, state-of-the-art dynamic model designed to analyse the domestic biofuels supply chain. Its primary focus revolves around addressing policy issues, evaluating their feasibility, and assessing potential side effects. BSM accomplishes this by integrating considerations of resources availability, physical and technological constraints, economic factors, behavioural aspects, and policy components (Newes, 2021). Multicriteria analysis (MCA) serves as a decision-making aid in a specific process, facilitating the incorporation of diverse criteria as per the perspectives of stakeholders within a unified analytical framework, thereby offering a holistic perspective (Morales-Máximo *et al.*, 2021). BSM and MCA are powerful integrated models that combines various dimensions to provide a more representative comprehension of biomass potential assessment for bioenergy. Various resource-focused and demand-driven assessment models are frequently used in the literature, including allometric equations, the Biomass Inventory and Mapping Tool (BIMAT), Carbon Balance Model (CBM-CFS3), Biomass Supply Model (BIOS), Geographic Information Systems (GIS), Life Cycle Assessment (LCA), and Modelling Based on Climate-Sensitive Processes (PBM) to assess biomass potential for bioenergy. However, it's important to note that resource-focused and demand-driven models generally fall short in capturing all the sustainability elements expected in an ideal bioenergy assessment (Batidzirai *et al.*, 2012).

To challenge this, authors often combine two or three methods to account for a large number of sustainability criteria. For example, statistical-focused models may be combined with Multicriteria Analysis to for a large number of sustainability criteria considerations. Allometric equations are used to estimate biomass by establishing quantitative relationships between plant characteristics such as diameter and height and biomass (Sebrala *et al.*, 2022). Allometric models are predictive models focusing on dendrometric variables as biomass predictors. They do not integrate a complexity of variables explaining the spatiotemporal dynamic of biomass potential. These equations allow specific data to be extrapolated to estimate the total biomass in a given area. In addition, BIMAT provides precise spatial data, allowing detailed visualization of biomass distribution (Pati *et al.*, 2022). Furthermore, CBM-CFS3 assesses the carbon balance in forest ecosystems, providing information on forest growth and biomass storage (Li *et al.*, 2022). This helps understand how much carbon is absorbed by the forest through photosynthesis and how much is released through processes such as respiration and decomposition. Along the same lines, BiOS evaluates the processes of biomass production, harvesting and supply, thereby contributing to an overall assessment (Levine *et al.*, 2021). GIS are increasingly used for spatial analysis of biomass data, providing tools for understanding biomass distribution (Ukoba *et al.*, 2023; Zyadin *et al.*, 2018). LCA assesses the environmental impact of biomass by considering factors such as biomass production and its use. From a broader perspective, LCA is used to assess the environmental impact of biomass over its entire life cycle, integrating factors such as production and competition uses. This provides a comprehensive perspective of the environmental implications associated with the use of biomass. In parallel, PBM takes into account climatic influences on biomass. By integrating climatic factors, the framework developed by Liu. adds an additional dimension to the estimation of the environmental impact of biomass (Liu *et al.*, 2020). The framework includes six impact components, such as fossil fuel-derived greenhouse gas emissions, biogenic CO_2 emissions and carbon sequestration difference (Wang *et al.*, 2016). This allows a more precise assessment of the impacts of biomass use on climate change. Understanding the effects of climatic factors on regional biomass resources is crucial to improve environmental management and promote sustainable development of biomass resource use (Ashter, 2018; Bright *et al.*, 2012; Wang *et al.*, 2016).

The reviewed studies reveal a spatial variation in global bioenergy potential. America, particularly Mexico, demonstrated the highest potential from standing biomass (60,220 PJ), while Asia, especially China, exhibited the highest bioenergy potential from forestry residues (4,701 PJ). Comparing these values to those of previous studies on a global scale is challenging due to various factors contributing to discrepancies in biomass potential patterns. These factors encompass differences in timeframe, spatial coverage, methodology, vegetation types, and types of biomass, among others. Thus, it is imperative to standardize the sources of bioenergy resource potentials to facilitate geographical comparisons worldwide (Batidzirai *et al.*, 2012).

Conclusion and Research Perspectives

Our systematic review reveals several significant findings on biomass potential. Stand biomass receives the most attention in research due to its accessibility and economic viability, while forestry residues were underrepresented despite their bioenergy potential. Assessments often prioritized theoretical and technical potential over economic and environmental considerations, indicating a need for more balanced approaches. Major drivers of biomass potential include land use change, future wood energy demand, and wood processing technology. Social, climatic, and economic factors also play a growing role in assessing biomass potential, signaling a shift towards holistic evaluations. However, the study points out an underconsideration of economic factors in sustainability criteria, emphasizing the need for comprehensive financial assessments. Social and environmental aspects are more frequently considered, aligning with sustainable development goals. The impact of bioenergy development on climate, water resources, and biodiversity vary, underscoring the importance of studies context and the specific variables considered. However, the impact of bioenergy development is assessed to be beneficial for the climate but negative for water resources.

The research notes a prevalence of resource-based models over integrated models, although integrated models are more powerful to account for various sustainability criteria. Future studies assessing biomass potential are encouraged to give more consideration to forestry residues, prioritize sustainability criteria, and harmonize assessments for global comparisons. Economic considerations may be integrated into assessments, and a shift towards holistic evaluations that encompass economic, social, and environmental aspects are essential for sustainable bioenergy development. Bioenergy Scenario Model (BSM) and Multicriteria analysis (MCA) stand as powerful integrate models and maybe recommendable for a sustainable assessment of biomass for energy production.

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Appendix. The list of reviewed studies including their title and publication types

Authors	Year	Title	Type of article
Lu, Y., Zhang, Y., Ma, K.	2022	The effect of population density on the suitability of biomass energy development	Original article
Sena, K., Ochuodho, T.O., Agyeman, D.A., Contreras, M., Niman, C., Eaton, D., Yang, J.	2022	Wood bioenergy for rural energy resilience: Suitable site selection and potential economic impacts in Appalachian Kentucky	Original article
Słupińska, K., Wieruszewski, M., Szczypa, P., Kożuch, A., Adamowicz, K.	2022	Public Perception of the Use of Woody Biomass for Energy Purposes in the Evaluation of Content and Information Management on the Internet	Original article
Storms, I., Verdonck, S., Verbist, B., Willems, P., De Geest, P., Gutsch, M., Cools, N., De Vos, B., Mahnken, M., Lopez, J., Van Orshoven, J., Muys, B.	2022	Quantifying climate change effects on future forest biomass availability using yield tables improved by mechanistic scaling	Original article
Zhang, X., Wang, J., Strager, M.P.	2022	Industrial Development and Economic Impacts of Forest Biomass for Bioenergy: A Data-Driven Holistic Analysis Framework	Original article
Röder, M., Chong, K., Thornley, P.	2022	The future of residue-based bioenergy for industrial use in Sub-Saharan Africa	Original article
Tauro, R., Velázquez-Martí, B., Manrique, S., Ricker, M., Martínez-Bravo, R., Ruiz-García, V.M., Ramos-Vargas, S., Masera, O., Soria-González, J.A., Armendáriz-Arnez, C.	2022	Potential Use of Pruning Residues from Avocado Trees as Energy Input in Rural Communities	Original article
Garvie, L.C., Roxburgh, S.H., Ximenes, F.A.	2021	Greenhouse gas emission offsets of forest residues for bioenergy in queensland, australia	Original article
Morales-Máximo, M., García, C.A., Pintor-Ibarra, L.F., Alvarado-Flores, J.J., Velázquez-Martí, B., Rutiaga-Quiñones, J.G.	2021	Evaluation and characterization of timber residues of pinus spp. as an energy resource for the production of solid biofuels in an indigenous community in mexico	Original article
Malico, I., Gonçalves, A.C.	2021	Eucalyptus globulus coppices in portugal: Influence of site and percentage of residues collected for energy	Original article
Gómez-García, E.	2021	Estimation of primary forest harvest residues and potential bioenergy production from fast-growing tree species in NW Spain	Original article
Nonini, L., Fiala, M.	2021	Harvesting of wood for energy generation: a quantitative stand-level analysis in an Italian mountainous district	Original article
da Costa, T.P., Quinteiro, P., Arroja, L., Dias, A.C.	2020	Environmental comparison of forest biomass residues application in Portugal: Electricity, heat and biofuel	Original article
Dudek, T.	2020	The impacts of the energy potential of forest biomass on the local market: An example of South-Eastern Poland	Original article

Authors	Year	Title	Type of article
Flores Hernández, U., Jaeger, D., Samperio, J.I.	2020	Modelling Forest Woody Biomass Availability for Energy Use Based on Short-Term Forecasting Scenarios	Original article
Pergola, M., Rita, A., Tortora, A., Castellaneta, M., Borghetti, M., De Franchi, A.S., Lapolla, A., Moretti, N., Pecora, G., Pierangeli, D., Todaro, L., Ripullone, F.	2020	Identification of suitable areas for biomass power plant construction through environmental impact assessment of forest harvesting residues transportation	Original article
Zhang, F., Johnson, D.M., Wang, J., Liu, S., Zhang, S.	2018	Measuring the regional availability of forest biomass for biofuels and the potential of GHG reduction	Original article
Pokharel, R., Grala, R.K., Grebner, D.L.	2017	Woody residue utilization for bioenergy by primary forest products manufacturers: An exploratory analysis	Original article
Frombo, F., Minciardi, R., Robba, M., Rosso, F., Sacile, R.	2016	A dynamic decision model for the optimal use of forest biomass for energy production	Original article
Gao, J., Zhang, A., Lam, S.K., Zhang, X., Thomson, A.M., Lin, E., Jiang, K., Clarke, L.E., Edmonds, J.A., Kyle, P.G., Yu, S., Zhou, Y., Zhou, S.	2016	An integrated assessment of the potential of agricultural and forestry residues for energy production in China	Original article
Cummins, J., Skennar, C., Capill, L., Cassidy, M., Palmer, G.	2016	Using small hardwood logs to produce liquid fuels and electricity	Original article
Manolis, E.N., Zagas, T.D., Poravou, C.A., Zagas, D.T.	2016	Biomass assessment for sustainable bioenergy utilization in a Mediterranean forest ecosystem in northwest Greece	Original article
Malico, I., Gonçalves, A.C., Sousa, A.	2016	Assessment of the availability of forest biomass for biofuels production in southwestern Portugal	Original article
Turrado Fernández, S., Paredes Sánchez, J.P., Gutiérrez Trashorras, A.J.	2016	Analysis of forest residual biomass potential for bioenergy production in Spain	Original article
Kukrety, S., Wilson, D.C., D'Amato, A.W., Becker, D.R.	2015	Assessing sustainable forest biomass potential and bioenergy implications for the northern Lake States region, USA	Original article
Repo, A., Böttcher, H., Kindermann, G., Liski, J.	2015	Sustainability of forest bioenergy in Europe: Land-use-related carbon dioxide emissions of forest harvest residues	Original article
Paredes-Sánchez, J.P., Gutiérrez-Trashorras, A.J., Xiberta-Bernat, J.	2015	Wood residue to energy from forests in the Central Metropolitan Area of Asturias (NW Spain)	Original article
Kemausuor, F., Kamp, A., Thomsen, S.T., Bensah, E.C., Stergård, H.	2014	Assessment of biomass residue availability and bioenergy yields in Ghana	Original article
Sacchelli, S., Bernetti, I., De Meo, I., Fiori, L., Paletto, A., Zambelli, P., Ciolli, M.	2014	Matching socio-economic and environmental efficiency of wood-residues energy chain: A partial equilibrium model for a case study in Alpine area	Original article

Authors	Year	Title	Type of article
He, L., English, B.C., De La Torre Ugarte, D.G., Hodges, D.G.	2014	Woody biomass potential for energy feedstock in United States	Original article
Sacchelli, S., Zambelli, P., Zatelli, P., Ciolli, M.	2013	Biomasfor: An open-source holistic model for the assessment of sustainable forest bioenergy	Original article
Becker, D.R., Eryilmaz, D., Klapperich, J.J., Kilgore, M.A.	2013	Social availability of residual woody biomass from nonindustrial private woodland owners in Minnesota and Wisconsin	Original article
Pedroli, B., Elbersen, B., Frederiksen, P., Grandin, U., Heikkilä, R., Krogh, P.H., Izakovičová, Z., Johansen, A., Meiresonne, L., Spijker, J.	2013	Is energy cropping in Europe compatible with biodiversity? - Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes	Original article
Bouriaud, O., Ştefan, G., Flocea, M.	2013	Predictive models of forest logging residues in Romanian spruce and beech forests	Original article
Abt, R.C., Abt, K.L.	2013	Potential Impact of Bioenergy Demand on the Sustainability of the Southern Forest Resource	Original article
Jones, G., Loeffler, D., Butler, E., Hummel, S., Chung, W.	2013	The financial feasibility of delivering forest treatment residues to bioenergy facilities over a range of diesel fuel and delivered biomass prices	Original article
Alam, M.B., Pulkki, R., Shahi, C.	2012	Woody biomass availability for bioenergy production using forest depletion spatial data in northwestern ontario	Original article
Alam, M.B., Pulkki, R., Shahi, C., Upadhyay, T.	2012	Modelling woody biomass procurement for bioenergy production at the Atikokan Generating station in northwestern Ontario, Canada	Original article
Domke, G.M., Becker, D.R., D'Amato, A.W., Ek, A.R., Woodall, C.W.	2012	Carbon emissions associated with the procurement and utilization of forest harvest residues for energy, northern Minnesota, USA	Original article
Scarlat, N., Blujdea, V., Dallemand, J.-F.	2011	Assessment of the availability of agricultural and forest residues for bioenergy production in Romania	Original article
Levin, R., Krigstin, S., Wetzel, S.	2011	Biomass availability in eastern Ontario for bioenergy and wood pellet initiatives	Original article
Wu, J., Wang, J.X., McNeel, J.	2011	Economic modelling of woody biomass utilization for bioenergy and its application in central appalachia, USA	Original article
Perez-Verdin, G., Grebner, D.L., Sun, C., Munn, I.A., Schultz, E.B., Matney, T.G.	2009	Woody biomass availability for bioethanol conversion in Mississippi	Original article
Sasaki, N., Knorr, W., Foster, D.R., Etoh, H., Ninomiya, H., Chay, S., Kim, S., Sun, S.	2009	Woody biomass and bioenergy potentials in Southeast Asia between 1990 and 2020	Original article

Authors	Year	Title	Type of article
Smeets, E.M.W., Faaij, A.P.C.	2007	Bioenergy potentials from forestry in 2050: An assessment of the drivers that determine the potentials	Original article
Kumar, A., Adamopoulos, S., Jones, D., Amiandamhen, S.O.	2021	Forest Biomass Availability and Utilization Potential in Sweden: A Review	Review
Van Holsbeeck, S., Brown, M., Srivastava, S.K., Ghaffariyan, M.R.	2020	A review on the potential of forest biomass for bioenergy in Australia	Review
Pokharel, R., Grala, R.K., Latta, G.S., Grebner, D.L., Grado, S.C., Poudel, J.	2019	Availability of Logging Residues and Likelihood of Their Utilization for Electricity Production in the US South	Review
da Costa, T.P., Quinteiro, P., Tarelho, L.A.D.C., Arroja, L., Dias, A.C.	2018	Environmental impacts of forest biomass-to-energy conversion technologies: Grate furnace vs. fluidised bed furnace	Review
Pokharel, R., Grala, R.K., Grebner, D.L., Grado, S.C.	2017	Factors affecting utilization of woody residues for bioenergy production in the southern United States	Review
Zamar, D.S., Gopaluni, B., Sokhansanj, S.	2017	Optimization of sawmill residues collection for bioenergy production	Review
Immerzeel, D.J., Verweij, P.A., van der Hilst, F., Faaij, A.P.C.	2014	Biodiversity impacts of bioenergy crop production: A state-of-the-art review	Review
Jäppinen, E., Korpinen, O.-J., Laitila, J., Ranta, T.	2014	Greenhouse gas emissions of forest bioenergy supply and utilization in Finland	Review
Joshi, O., Grebner, D.L., Munn, I.A., Grado, S.C., Grala, R.K., Hussain, A.	2014	Factors influencing utilization of woody biomass from wood processing facilities in mississippi	Review
Parzei, S., Krigstin, S., Hayashi, K., Wetzel, S.	2014	Forest harvest residues available in Eastern Canada - A critical review of estimations	Review
Zambelli, P., Lora, C., Spinelli, R., Tattoni, C., Vitti, A., Zatelli, P., Ciolli, M.	2012	A GIS decision support system for regional forest management to assess biomass availability for renewable energy production	Review